U. S. DEPARTMENT OF AGRICULTURE
WEATHER BUREAU

FIRST REPORT
ON THE
RELATIONS BETWEEN CLIMATES AND CROPS
BY
CLEVELAND ABBE

Mrs J. G. Livesay

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A FIRST REPORT

ON

THE RELATIONS BETWEEN CLIMATES AND CROPS.

BY

CLEVELAND ABBE.

PREPARED UNDER THE DIRECTION OF

WILLIS L. MOORE,

Chief United States Weather Bureau.

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LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Weather Bureau, Office of the Chief,
Washington, D. C., August 1, 1905.

Hon. James Wilson,
Secretary of Agriculture, Washington, D. C.

Sir: I have the honor to submit the manuscript of a first report, by Prof. Cleveland Abbe, on the Relations Between Climates and Crops, and to recommend its publication as a bulletin of the Weather Bureau.

This paper is not designed as an original investigation, but as a summary of the views of the best experimentalists and observers, so far as those had been published up to 1891. A continuation of this study, bringing the subject up to date, is contemplated; but as the publication of this first portion has been frequently requested, it seems wise not to delay.

The author has intended to notice only those investigations that have given precise information as to specific plants or crops and specific localities, and has made a thorough search of all the more important literature, in so far as it was accessible to him; it is believed that the numerous extracts given by him will be gratefully received by those who have not access to the same volumes.

The work is prepared with the idea that it will be especially useful to the teachers of the agricultural colleges and the investigators of the agricultural experiment stations. Therefore only a limited edition is recommended.

As the memoir points out the importance of a climatic laboratory and the methods that must be pursued in order to evolve new varieties of crop plants adapted to special climatic conditions, I can but consider that you will recognize this memoir as a proper contribution to agriculture from the Weather Bureau.

Very respectfully,

Willis L. Moore,
Chief U. S. Weather Bureau.

Approved:
James Wilson,
Secretary.

PREFACE.

Several experts in agricultural science having stated to me their need of a systematic summary of the present state of our knowledge with regard to the specific influence of climate in agriculture and its relation to or absolute effect on the percentages of the resulting harvest, and the subject being one in which I had long been interested, I therefore presented the matter to the Chief Signal Officer, who thereupon issued an instruction, dated February 25, 1891, authorizing me to prepare this work, completing it before June 30 of that year. The present report is a rapid compilation from a wide range of sources, and presents a preliminary view of the condition of our knowledge at that time as to the effect of climate upon the growth and distribution of our staple crops. As far as practicable I have presented, in the words of the respective authors, the results of their own investigations on the points at issue, my own duty being not to undertake any extensive original study, but to merely connect their results together in a logical manner, to collect data for future general use, and to suggest, or stimulate, further inquiry on the points here presented. I regret that the report could not have been published in 1891, as many of the ideas presented therein have by delay thus been withheld from their practical applications to the benefit of agriculture.

As the study of phenology and agriculture, in the modern spirit, has been cultivated for over a century in Europe, much of our knowledge must be drawn from European literature, which is really far too extensive to be satisfactorily summarized in the time and space at my disposal. Originally it was my hope to introduce into this report a summary of the large and sadly scattered literature of American phenology, including the dates of blossoming and ripening both of native and cultivated plants, enlarging the work already done in this line by F. B. Hough for the State of New York; but I did not succeed in completing this part of the work, and reserve it for a future occasion. Requests for phenological observations in the United States have been frequently made since 1800, and large collections of data exist in manuscript and print sufficiently extensive to justify the hope that they may prove worthy of a study as elaborate

as that which European observations have received at the hands of the lamented Linsser.

The very extensive problem suggested by the title of this report involves, first, a general study of meteorology in its relations to vegetable and animal life; second, the determination of the effect of climate upon the growth and distribution of staple crops; third, the determination of the climatic conditions and the localities best suited to the growth of special varieties of plants and seeds; fourth, the statistics of the extent of the areas best adapted to each of the more important crops; fifth, the separate and the combined effects of temperature, rainfall, and sunshine, both in their normal and abnormal proportions, upon the annual yields of the staple crops. But such study necessitates great labor and much time, and as the first step in any such investigation consists in the critical examination of the work already done by others, in order to prevent unnecessary duplication and avoid the troubles that others have experienced, therefore the reader must consider this first report as only a brief introduction to our knowledge of the relations between climates and crops.

Three ways are generally recognized as affording our only methods of advancing our knowledge of our subject, viz, physiological, experimental, and statistical. I shall therefore endeavor to present the question of climates and crops from these three points of view.

1. The physiological studies of many botanical physiologists, under the leadership of Prof. Julius von Sachs, of the Botanical Institute at Würzburg, Germany, have given us an insight into the method of growth of plants and the conditions upon which successful agriculture must depend. Their conclusions, based upon microscopic examination, delicate measurements, and detailed study of all the minutiæ in the life of a plant, have given occasion to the development of what may be called a theory of vegetable life, which, however, is still far from having reached a perfect stage of development. Under this head I have collected observations relative to the germination of seeds, the flow of the sap, the action of sunlight on the leaves, the absorption of moisture by the roots, the transpiration from the leaves, the ripening of the seeds, the nutritious value of the crop, and the acclimatization of plants.

2. The experimental method of determining the relations of crops and climates is that practiced at agricultural experiment stations and also in the botanical or biological laboratories that are so plentiful in the United States and in Europe. In these institutions special seeds are sown with special care, either in the open air in small plats of ground or in culture pots in rooms where the temperature, moisture, and other conditions are under control. The numerous abstracts that I have presented in this report tend to show the effect of varying conditions upon the resulting crops, and I must agree heartily

with De Candolle in his plea for a climatic laboratory. It is evident that in such an institution one may reproduce to perfection the climatic conditions under which a given seed was grown, and thus insure a maximum crop; or, on the other hand, by successive cultivations, under successive slight changes in the artificial climate, may so modify the seed as to produce a new variety with a fixed habit of growth adapted to any natural climate that the farmer has to deal with. The laws of acclimatization that naturally follow from Linsser's investigations, and, in fact, from general experience in all parts of the world, point to this as a most important field of future usefulness. It is thus that we may hope to accelerate the natural course, which, on the one hand, has already produced grains adapted to the Russian steppes, and, on the other, will eventually evolve those adapted to the vicissitudes of our own arid regions and possibly our severe Alaskan climate.

3. The statistical method of ascertaining the effect of a climate on the resulting crop consists in comparing the statistics of the successive annual harvests in the country at large with the statistics of the prevailing climatic conditions. At the close of this report I have given a large collection of data of this kind, sufficient, I think, to show that this method is very unsatisfactory because of our ignorance of the many details that must be considered in discussing the statistical figures. I have compiled these elaborate tables for the United States from the data given by the former Statistician of the Department of Agriculture, Mr. J. R. Dodge, and his able assistant, Mr. Snow, and have indicated a method of treating these figures which will, I think, eventually give us the best results that they are capable of affording, and will be, perhaps, sufficiently accurate for the needs of the farmer, the merchant, and the statesman, but which can scarcely respond to the exact demands of agricultural physics. The great collection of data given in the reports of the Tenth and Eleventh censuses of the United States for the crop years 1879 and 1889 will, I hope, tempt some one to an extended study for those years.

I shall not devote much space to the question of the relative influence of forests and cultivated fields on the temperature and moisture of the local air. This has become a special study on the part of those devoted to forestry, and the papers of Professor Ebermayer (1873), Muttrich (1880), Nordlinger (1885), and others [a] teem with figures to show that in the heart of an extensive forest the mean daily variations of temperature or the range from minimum to maximum is, on the average, from 2° to 5° C. less than in the open air just outside the forest, while a similar difference of only 1° to 2° C. exists for the

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[a] The full titles of the works referred to in this report will be found in section on "Bibliography," Part IV.

annual ranges of temperature. Some attempts have also been made to show that in a forest region more rain falls than in adjacent open fields; but this I shall not further consider, as I have elsewhere shown that the measured differences are all due to the influence of the wind on the catch of the rain gage and have nothing to do with rainfall itself. All reliable observations show that the percentage of moisture in the soil is larger under the forest than in the open air, and all investigations show that the temperature of the soil is far more uniform under the forest than in the full sunshine.

The proper conclusion to draw from these forest studies, in so far as they relate to the question of the influence of climate on crops, is simply that plants growing within the influence of a forest have a somewhat different climate from those growing in the open field. The amount of this influence will become a proper study when any important crop is cultivated within a forest or under its influence, which, however, is not now generally the case.

The inverse question as to the influence upon general atmospheric phenomena of the temperature and moisture of the thin layer of quiet air within a region covered with a forest is one that may be relegated to the future as being of minor importance in dynamic meteorology and of still less importance in agricultural climatology.

On the other hand, the distribution and quality of forest trees affords a very important illustration of climatic influence. Indeed, the forests themselves furnish a most important crop of lumber and firewood, perhaps the most valuable crop recorded in the statistics of the country, and one whose relation to climate must be important, but, unfortunately, the statistics of annual forest growth are not yet available for this study. I have, therefore, deferred the consideration of this branch of our subject to a future date, when perhaps American forestry will be more fully developed.

I shall omit the consideration of theories and experiments as to the artificial improvement of the weather, especially the production of rainfall, protection from hail and lightning, and the amelioration of our hot winds. Although this subject is alluring, I hope the common sense of the agricultural community will eventually indorse my conviction that, for the present, our wisest plan is to confine our study closely to, first, the influence of sunshine, heat, moisture, and atmosphere on the growth of plants, on the nature of the seed, and on the character of the crops; second, the influence of the quality of the seed itself and of the richness of the soil on the crop; third, how to choose our seed, cultivate the ground, and protect the plant from frost, birds, insects, fungi, etc., so as to secure a good crop in spite of adverse natural climatic conditions.

In general, I have labored to put my data and conclusions before the reader so fully that, if a student, he may utilize this report as a

basis for further generalizations, or, if a farmer, he may derive many suggestions, hints, and rules by which to improve his methods.

Very few appreciate the extensive range of edible plants, but the lists given by E. L. Sturtevant (Agr. Sci., Vol. III., p. 174) suggest that we have in the botanical world an almost unexplored field from which to recover for the use of civilized man an endless variety of foods and fruits unknown to our present cuisine and table. Sturtevant enumerates in detail the 210 natural orders of plants recognized by botanists from the days of Linnæus to those of Bentham and Hooker. These orders include 8,349 genera and 110,663 species, and Sturtevant shows that the edible plants include only 4,233 species, representing 170 of these orders, so that only about 3½ per cent of the known species of plants are now being used as food—most of them, of course, to a very slight extent, only as auxiliaries to the principal foods.

The food plants extensively cultivated by man include only 1,070 species; that is to say, less than 1 per cent of all known species are cultivated anywhere throughout the known world, and those actually in ordinary use in European and American kitchen gardens represent only 211 species. The preceding numbers all refer to the phenogams, but Sturtevant gives supplementary lists covering the lower order of plants.

Therefore it would seem that the present condition of agriculture and the present extent of our available vegetable foods is limited not so much by our climate and soil as by our ignorance of the laws of nature affecting plant life. We may not control the climate, but we may rear natural plants and adopt rational methods of modifying them by cultivation until they and we become quite independent of the vicissitudes of drought and frost.

In conclusion I gratefully acknowledge the enthusiastic assistance that I have received from Mrs. R. S. Hotze as translator, and Mr. E. R. Miller in the preparation of the index.

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Chapter I.

GENERAL REMARKS.

It is not possible to conceive of an intelligent solution of the complex problems offered by plant life in the open air and cultivated fields without first considering the innumerable experiments that have been made by experimental botanists. It is therefore necessary for the student and the practical man alike to know something of the laws of growth, as presented in the elaborate treatises by Sachs, Vines, Goodale, and others. I will at present simply collate those special results that bear upon crops as the final object of agriculture and confine myself very closely to the relation between the crop and the climate, in order to avoid being drawn into the discussion of innumerable interesting matters which, although they may affect the crop, yet are understood to be outside the province of climatology. By this latter term I understand essentially the influence on the plant of its inclosure, i. e., the sky or sunshine, soil, temperature, rainfall, and the chemical constitution of the air, either directly or through the soil.

THE VITAL PRINCIPLE—CELLULAR AND CHEMICAL STRUCTURE.

The growth of a plant and the ripening of the fruit is accomplished by a series of molecular changes, in which the atmosphere, the water, and the soil, but especially the sun, play important parts. In this process a vital principle is figuratively said to exist within the seed or plant and to guide the action of the energy from the sun, coercing the atoms of the soil, the water, and the air into such new chemical combinations as will build up the leaf, the woody fiber, the starch, the pollen, the flower, the fruit and the seed.

A climate that is favorable to a special crop is one whose vicissitudes of heat and rain and sunshine are not so extreme but that they can easily be utilized by the sunbeams in building up the plant. An unfavorable climate is one whose average conditions or whose extreme vicissitudes are such that the vitality of the plant—namely, its power to grow—can not make headway against them. In extreme cases, such as frosts, sudden thaws, and great droughts, the climate may even destroy the organic material that had already been formed in the plant.

No plant life, not even the lowest vegetable organism, is perfected except through the influence of the radiation from the sun. It may need the most intense sunlight of the Tropics, or it may need only the diffuse and faint light within dark forests or caves. Heat alone may possibly suffice for the roots and certain stages of growth, but a greater or less degree of light—i. e., energy delivered in short-wave length or rapid periodic oscillations—is necessary for the eventual maturity. The radiation from any artificial light, especially the most powerful electric light, will accomplish results similar to that of sunlight; therefore, it is not necessary to think that life or the vital principle is peculiar to or emanates from the sun, but on the contrary that living cells utilize the radiations or molecular vibrations so far as possible to build up the plant.

We know nothing about the nature of this vital principle, but we can, by the microscope, demonstrate that the essential ultimate structure of the plant or seed is a minute cell, namely, a very thin skin or film or membrane inclosing a minute portion of matter consisting of mixed liquids and solids. This skin is called the wall of the cell; in the early growth of the cell its inclosed liquid is called the protoplasm. By crushing many such young cells we may obtain enough of either part to make a chemical examination and find that the cell wall is a complex chemical substance called cellulose, composed of carbon, hydrogen, and oxygen. By molecules this compound is $C_{18}H_{30}O_{15}$; by weight cellulose has C 44.44, H 6.17, O 49.39 per cent. As the cells become older their walls become thicker and are incrusted internally with additional matters, such as gums, resins, etc., until the cell wall refuses to perform its original functions. Such old cells are not easily digested by man or animals and are not considered as food or reckoned among the food crops, but young cells in succulent stems, leaves, and fruits, or the crushed cells of seeds and grains, are nutritious food. Flax, cotton, jute, straw, wood pulp, and many other mature dried cells form the important crops of textile fibers.

The protoplasm within the cell is generally an albuminous com-

pound or albuminoid, viz, besides having carbon, hydrogen, and oxygen, it also contains considerable nitrogen and a little sulphur or phosphorus or iron or other substances, thus forming albumen, whose chemical constitution is expressed by the approximate molecular formula $C_{72}H_{110}N_{18}O_{22}S_1$, or by weight C 53, H 7, N 16, O 22, S 1 per cent. Possibly this molecular formula is more properly written $3(C_{24}H_{38}N_6O_8)$, plus the addition of sulphur compounds such as to make the whole become as before written. Mulder supposed that a certain substance which he called proteine, and whose composition is supposed to be $C_{36}H_{26}N_6O_{10}$, is the basal molecule of albumen; two such molecules, with additional quantities of nitrogen, hydrogen, and oxygen, combined with a little sulphur, phosphorus, iron, or other mineral, make up, according to him, the constitution of the ordinary albuminoid. But his views are not considered altogether acceptable.

The constituent chemical elements contained in cellulose are precisely the same as those of starch, whose formula is $C_6H_{10}O_5$, but the arrangement of the atoms and molecules among themselves is undoubtedly very different, so that the physical and chemical properties of starch and cellulose are very different. Starch, diastase, and cellulose may be considered as substances composed of molecules whose internal structures are respectively more and more complex; in the molecules of each of these substances the carbon, hydrogen, and oxygen are in the same proportions relative to each other both by number and by weight, but a molecule of diastase has twice and one of cellulose three times as many atoms as a molecule of starch. The composition of pure water is represented by the molecular formula H_2O_1, or by weight H 11, O 89, so that starch may be considered as a compound of 6 atoms of carbon with 5 molecules of water. From the same point of view diastase would be compounded of 12 atoms of carbon and 10 molecules of water, while cellulose would consist of 18 atoms of carbon and 15 molecules of water. These three substances are therefore called carbohydrates, as though carbon combined with water were to be considered as carbon combined with hydric acid. This term is not to be confounded with the word "hydrocarbon," which is applied to any compound of hydrogen and carbon, which, when combined with water or other molecules, forms a very different series of chemicals, such, for example, as C_4H_6, which is a hydrocarbon and when combined with 4 molecules of water or hydric oxide forms alcohol, making the latter, as it were, a hydrate of a hydrocarbon.

The approximate percentages by weight of the cellulose found in plants and vegetables dried at a temperature of 212° F. and the per-

centage of albuminous compounds for air-dried crops are given as follows:

Plant.	Cellulose (dried at 212°).	Albuminoids (air dried).	Plant.	Cellulose (dried at 212°).	Albuminoids (air dried).
Potato tubers	1.1		Beans		24-41
Wheat kernels	3.0	11-20	Red clover hay	34.0	12-20
Maize kernels	5.5	10-16	Timothy	23.0	
Barley kernels	8.0	12-16	Oat straw	40.0	
Oat kernels	10.3	11-17	Wheat straw	48.0	3- 4
Buckwheat kernels	15.0	10-14	Rye straw	54.0	3- 4
Peas		22-36			

This crude chemical analysis of the walls and of the contents of the crushed cells tells us nothing of the life that had previously resided in the uncrushed organisms, but prepares us for the statement that the development of a plant implies a great amount of work done among the molecules in rearranging them into the places where they are needed. These molecules come from the simpler atoms in the soil, the air, and the rain water, but the force and energy that does the work of building them up comes, so far as we know, from the sunshine. It is a case of the transformation of energy. Within the cells of a plant the molecular energy, or the so-called "radiant energy," that would otherwise produce the phenomena of heat and light is transformed into chemical activity and produces the new molecular compounds that we use as food. We and other animals can not produce these compounds in our own bodies, but we can utilize them if they are not injured in the process of cooking.

GENERAL RELATIONS OF THE SEED AND PLANT TO THE AIR AND THE SOIL.

RESPIRATION.

It is known that in the act of germination the seed absorbs oxygen from the air contained in the interstices of the soil and that very few seeds will germinate when the soil and the water are deprived of air or free oxygen.

As to the full-grown plant, it is commonly said to absorb carbonic-acid gas from the air through its leaves and to exhale oxygen. The investigations of Moisson tend to modify this statement and show that at low temperatures there is more oxygen absorbed than there is carbonic-acid gas produced, while at high temperatures the reverse is true. For each plant there is a certain temperature at which each volume of carbonic-acid gas absorbed is replaced by an equal volume of oxygen exhaled by the leaves. Thus in the case of the *Pinus pinaster* for every 100 volumes of oxygen absorbed there are 50 volumes of carbonic-acid gas exhaled at 0° C. temperature, but 77 volumes at 13° C. and 114 volumes at 40° C.

Evidently this whole process of respiration depends largely upon the temperature of the air and is more active as the temperature increases. It goes on both in darkness and in light, but with this difference—that in darkness more carbonic-acid gas is given out than the oxygen that is absorbed, whereas, on the other hand, under the influence of light more oxygen is given out than the carbonic-acid gas that is absorbed. Both these processes are stimulated by heat. The assimilation or nutrition of the plant depends upon this mechanical influence of light in disengaging oxygen and "fixing" the carbon of the gas in the cells of the plant. Plant respiration is accompanied by two distinct but correlated phenomena, which are defined by Marie-Davy (1882) as "evaporation" and "transpiration."

Evaporation.—This is a purely physical phenomenon. All bodies lose water from their external surfaces when in contact with dry air, and do so faster in proportion as the wind is stronger and the air is drier. Evaporation takes place for dead and living surfaces alike.

Transpiration.—This is a physiological and not a purely physical phenomenon. It occurs only in living plants and under the influence of light; it is independent of the dryness of the air and is only indirectly dependent on temperature. It is intimately connected with assimilation, since by its means materials are furnished to complete the work of the growth of the plant.

DRYNESS, TEMPERATURE, AND VELOCITY OF THE WIND.

The evaporation from the leaves, the flow of sap, and the development of the plant depend almost as much on the wind and the dryness of the air as they do on the temperature of the air considered by itself, since all these are necessary in order to bring the supply of nutritious water up to the leaf. Therefore, the temperature of the air must not be considered as the only important climatic element controlling vegetation. At the time of the bursting of the buds in the spring, when no leaves are on the trees and when the respiration of the plant and the evaporation are at their minimum, the temperature and dryness of the air have their least influence, while the temperature and moisture of the soil may have their maximum relative importance. These latter are the elements that determine how much water shall be absorbed and pushed upward as sap. It is under the influence of this upward pressure of the sap that the sunlight manufactures the first buds and leaves. The temperature of the air flowing among the branches and buds may have any value without seriously affecting the development of the plant, provided it is above freezing and below a destructive temperature, such as 120° F., and above a destructive dryness, such as 5 or 10 per cent of relative humidity. Ordinarily a warm spring day implies a warm, moist soil and a warm,

moist atmosphere. Man naturally observes first the latter feature, which is so important to him, and then associates it with the budding of the plant, but he recognizes his mistake when he considers that the plant is firmly established in the earth and that its nourishment and growth must depend primarily on the condition of the soil and roots.

TEMPERATURE AND MOISTURE OF THE SOIL.

The temperature of the soil a short distance below the immediate surface does not depend, by way of cause and effect, primarily on the temperature of the air. It is not warmed or cooled appreciably by conduction of atmospheric heat, but by direct absorption or loss of the radiation that falls upon it. To a slight extent (perhaps 5 per cent) this sunshine is reflected from the surface particles of the ground according to the laws of simple reflection; the remainder is absorbed by the surface and warms it. This warmed surface layer immediately radiates back a small quantity (10 per cent) as long waves into the atmosphere and through that into space, since the atmosphere does not absorb these long waves, but it gives up a larger part, perhaps 50 per cent, by conduction to the adjacent lowest layer of air, which being thus warmed quickly rises and by convection distributes this 50 per cent of heat throughout the atmosphere, whence it is eventually radiated back into space. The remaining 40 per cent of the solar heat is by conduction carried downward through the solid earth; a large portion is consumed in the evaporation of soil water and returns to the atmosphere with the aqueous vapor; the rest goes on downward, warming up the soil until it arrives at a layer 30 to 50 feet below the earth's surface, where the gradient of temperature just in front of it is the same as that just behind it. Here the heat would accumulate and push its way still deeper were it not that by this time, in most cases, the diurnal and annual changes of temperature at the earth's surface, where this heat wave started, have brought about a deficiency just below the earth's surface; consequently the heat that had reached the depth of 30 or 50 feet now finds the temperature gradient just above it beginning to reverse, wherefore this heat begins to flow back, upward, and outward. In this manner the temperature of the ground increases downward to a depth of a few yards during certain months and then upward during other months, in diurnal and annual fluctuations interspersed with irregular changes, depending on cloud and wind and rain, all of which are easily recognized by examining any system of curves representing the earth temperatures at different depths throughout the year.

The ground is warmed by the air only in case the temperature of the surface soil is lower than that of the air, and, although this happens frequently, yet the quantity of heat thereby communicated

to the ground is comparatively slight, owing to the slow conductivity of the soil and the small specific heat of the atmosphere. This point has been carefully developed by Maurer, of Zurich (1885). But when rain and snow fall, then the latent heat formerly contained in the atmospheric vapor is quickly given to the surface soil and directly conducted deeper into the ground, and the latter is warmed or cooled according as the rain or snow is warmer or cooler than it. In general, the warming of the soil by warm rain is less important than the cooling by cold rains, melting snows, and evaporating winds.

CLOUDINESS.

When clouds intervene the soil receives a smaller proportion of direct solar heat, and the proportion diminishes as the thickness of the cloud layer increases or as the proportion of cloudy sky to clear sky increases. We may adopt the approximate rule that the warming effect of the sunshine is inversely as the cloudiness of the sky within 45° of the zenith; thus for a sky covered by 10 cumulus or 10 stratus the direct solar heat at the ground is 0; for 10 cirrus or cirro-cumulus or cirro-stratus the solar heat is about 5, while for 0 cloudiness the radiation that the observer receives is 10.

SOIL THERMOMETERS.

The motions of the clouds do not affect the sum total of the intensity of the sunshine, but the variations of cloudiness are so important that it is best to make use of some form of sunshine recorder or, better still, some form of integrating actinometer as a means of determining the relative effectiveness of the sunshine for any hour or day. If any such instrument shows that during any given hour, with the sun at a known altitude, the duration of the effectiveness of the sunshine was the nth part of the maximum value for clear sky, then we may assume that the heating effect of the sun on the surface of the soil was the nth part of its maximum value and may thus ascertain and, if need be, approximately compute the irregularities of the diurnal waves of heat that penetrate the soil. But these irregularities are directly shown by thermometers buried in the soil at different depths, and the observation of such soil thermometers is an essential item in the study of climate and vegetation. The absence of these observations has necessitated much labor in unsatisfactory efforts to obtain the approximate soil temperatures from the ordinary observations of air temperature, radiation thermometers, clouds and sunshine.

Fortunately the agricultural experiment stations of the United States have begun the observation of soil temperatures as distin-

guished from the deep-earth temperatures that have for a century past interested the student of terrestrial physics but do not affect agriculture. I shall hereafter give a synopsis of such records so far as they are available to me; but so much agricultural data has been collected, both in Europe and America, without corresponding soil temperatures that we also need the data and methods that may be used for estimating soil temperatures from ordinary meteorological observations.

SUNSHINE.

Climatology usually considers the temperature of the air as given by thermometers that are shaded from the effect of sunshine; this is the temperature of the air very nearly as given by the whirled or ventilated or sling thermometers and is that which is needed in dynamic meteorology. But the sunshine produces important chemical effects besides its thermal effects, and these have no simple relation to each other. It is therefore very important that we have some method of recording the duration, intensity, and quality of the total or general radiation that the plant receives from the sun and from the sun and the sky combined. Up to the early part of the nineteenth century the optical and thermal effects of sunshine were spoken of as due to certain imponderable forces called light and heat that were supposed to be combined in the complex solar rays, but which can be separated from each other. But we now believe it to be correct to speak of the sunshine as a complex influence, a radiation of energy, whose exact nature is problematical, but whose mechanical effects when it acts upon terrestrial matter we know, measure, and study as the phenomena of light, heat, electricity, gravitation, chemism, and vitality.

DISTRIBUTION OF CLIMATIC ELEMENTS RELATIVE TO THE LIFE OF THE PLANT.

As before stated, plants respire during both day and night. The pores of the leaves are always absorbing and emitting gases, but when the sun shines on the leaves, and more especially with the help of the yellow part of the solar spectrum, the chlorophyl in the leaf cells is able to decompose the carbonic acid absorbed by the plant, retaining carbon and rejecting the oxygen.

So long as the plant absorbs more carbon from the air and more nitrogen from the soil than it loses by any process it is continually increasing its leaf surface and the nutrition in its sap, laying up a store of nutriment for future use. This process ceases in the case of annual plants when the seed or grain or fruit begins to ripen; from this time forward the seed makes a steady draft upon the nutriment already stored up in the plant which goes to perfect the seed. In

this season of its growth the plant really needs less water than before, but still its roots have the same power of absorbing water, and if the sap is thus diluted there results a seed or fruit that is heavy with an excess of water. Of course this water will dry out, if it has an opportunity, after the harvest, but if it has no opportunity, on account of damp weather, it will remain in the seed and render the latter more subject to injury from fungi, whose spores are always floating in the air seeking a moist nidus or resting place favorable to their growth. Such moist seeds give a heavy, green harvest, but a light dried crop.

Thus it happens that the distribution of atmospheric heat, and moisture, as to time, is quite important in its effect on the local harvest.

Apparently the time of ripening of the harvest depends wholly upon the chronological distribution of water and sunshine, but the quantity and quality of the harvest, which are the important practical results to the farmer, depend upon the nutrition carried into the plant by the water that is absorbed by the roots.

IRRIGATION.

The determination of the right time for irrigation and of the proper quantity of water, in order to produce the best crop in soil of a given richness is the special problem of those planters who depend mostly upon irrigation for successful agriculture. In general it may be said that our ordinary seeds have long since been selected and acclimatized with a view to success in a climate where abundance of moisture is available at the proper season. Hence our crops are not so likely to be injured by excess of rain as by deficiency or drought. Therefore in almost every section, from the Rocky Mountains to the Atlantic, the highest success can only be attained by making provision for artificial irrigation in times of drought. The exact times and quantities of irrigating water depend upon the seed, the soil, and the evaporation, which latter is due to dryness of the air, the velocity of the wind, and the character of the soil; but when artificial watering or irrigation is needed to supplement natural rain one must seek to approximate as closely as practicable to the conditions presented in the countries where the seed originated, and especially the conditions presented during the seasons in which the given seed produced the best crops.

IMPORTANCE OF CLIMATIC LABORATORIES.

The studies that we are entering upon are greatly facilitated by experiments on a moderate scale under conditions that are under the control of the investigator, and free from the irregularities of open-air agriculture. The laws of nature can only be found out by questioning nature, as it were, by means of test experiments. Our present

needs in this respect are even more urgent now than they were thirty years ago, and I can not do better than to reprint and indorse the following appeal first made in an address by A. de Candolle in 1866:

It appears to me, however, that botanic gardens can be made still more useful in carrying out physiological researches. For instance, there is much yet to be learned on the mode of action of heat, light, and electricity upon vegetation. I pointed out many of these deficiencies in 1855 in my Géographie Botanique Raisonnée. Ten years later Prof. Julius Sachs, in his recently published and valuable work on Physiological Botany, remarks much the same deficiencies, notwithstanding that some progress has been made in these matters. The evil consists in this, that when it is desired to observe the action of temperature, either fixed or varied, mean or extreme, or the effect of light, it is exceedingly difficult, and sometimes impossible (when observations are made in the usual manner), to eliminate the effects of the constant variations of heat and light. In the laboratory it is possible to operate under more exactly defined conditions, but they are rarely sufficiently persistent; and the observer is led into error by growing plants in too contracted a space, either in tubes or bell glasses. This last objection is apparent when it is wished to ascertain the influence of the gases diffused in the atmosphere around plants, or that of the plants themselves upon the atmosphere.

Place plants under a receiver, and they are no longer in a natural condition; leave them in the open air, and the winds and currents, produced at each moment of the day by the temperature, disperse the gaseous bodies in the atmosphere. Everyone is aware of the numerous discussions concerning the more or less pernicious influence of the gases given off by from certain manufactories. The ruin now of a manufacturer, now of a horticulturist, may result from the declaration of an expert; hence, it is incumbent on scientific men not to pronounce on these delicate questions without substantial proof.

With a view to these researches, of which I merely point out the general nature, but which are immensely varied in details, I lately put this question: "Could not experimental greenhouses be built, in which the temperature might be regulated for a prolonged time, and be either fixed, constant, or variable, according to the wish of the observer?" My question passed unnoticed in a voluminous work where, in truth, it was but an accessory. I renew it now in the presence of an assembly admirably qualified to solve it. I should like, were it possible, to have a greenhouse placed in some large horticultural establishment or botanic garden, under the direction of some ingenious and accurate physiologist and adapted to experiments on vegetable physiology; and this is, within a little, my idea of such a construction:

The building should be sheltered from all external variations of temperature, to effect which I imagine it should be in a great measure below the level of the ground. I would have it built of thick brickwork, in the form of a vault. The upper convexity, which would rise above the ground, should have two openings—one exposed to the south, the other to the north—in order to receive the direct rays of the sun, or diffused light. These apertures should each be closed by two very transparent glass windows, hermetically fixed. Besides which, there should be on the outside means of excluding the light,

in order to obtain complete darkness, and to diminish the influence of the variations of temperature when light is not required. By sinking it in the ground, by the thickness of its walls, and by the covering of its exterior surfaces with straw, mats, etc., the same fixed degree of temperature could be obtained as in a cellar. The vaulted building should have an underground communication with a chamber containing the heating and the electrical apparatus. The entrance into the experimental hothouse should be through a passage closed by a series of successive doors. The temperature should be regulated by metallic conductors, heated or cooled at a distance. Engineers have already devised means by which the temperature of a room, acting on a valve, regulates the entry or exit of a certain amount of air, so that the heat regulates itself. Use could be made of such an apparatus when necessary.

Obviously, with a hothouse thus constructed, the growth of plants could be followed from their germination to the ripening of their seeds, under the influence of a temperature and an amount of light perfectly definite in intensity. It could then be ascertained how heat acts during the successive phases from sowing to germination, from germination to flowering, and from this on to the ripening of the seed. For different species various curves could be constructed to express the action of heat on each function, and of which there are already some in illustration of the most simple phenomena, such as germination, the growth of stems, and the course of the sap in the interior of certain cells. We should then be able to fix a great number of those minima and maxima of temperature which limit physiological phenomena. Indeed, a question more complicated might be investigated, toward the solution of which science has already made some advances, namely, that of the action of variable temperatures; and it might be determined if, as appears to be the case, these temperatures are sometimes beneficial, at other times injurious, according to the species, the function investigated, and the range of temperature. The action of light on vegetation has given rise to the most ingenious experiments. Unfortunately these experiments have sometimes ended in contradictory and uncertain results. The best ascertained facts are the importance of sunlight for green coloring, the decomposition of carbonic-acid gas by the foliage, and certain phenomena relating to the direction or position of stems and leaves. There remains much yet to learn upon the effect of diffused light, the combination of time and light, and the relative importance of light and heat. Does a prolonged light of several days or weeks, such as occurs in the polar regions, produce in exhalation of oxygen, and in the fixing of green matter, as much effect as the light distributed during twelve-hour periods, as at the equator? No one knows. In this case, as for temperature, curves should be constructed, showing the increasing or diminishing action of light on the performance of each function; and as the electric light resembles that of the sun, we could in our experimental hothouse submit vegetation to a continued light.

A building such as I propose would allow of light being passed through colored glasses or colored solutions, and so prove the effect of the different visible or invisible rays which enter into the composition of sunlight. For the sake of exactness nothing is superior to the decomposition of the luminous rays by a prism, and the fixing the

rays by means of the heliostat. Nevertheless, a judicious selection of coloring matters and a logical method of performing our experiments will lead to good results. I will give as proof that the recent most careful experiments concerning the action of various rays upon the production of oxygen by leaves and upon the production of the green coloring matter have only confirmed the discoveries made in 1836, without either prism or heliostat, by Professor Daubeny, from which it appears that the most luminous rays have the most power, next to them the hottest rays, and lastly those called chemical.

Doctor Gardner in 1843, Mr. Draper immediately after, and Dr. C. M. Guillemin in 1857, corroborated by means of the prism and the heliostat the discovery of Doctor Daubeny, which negatived the opinions prevalent since the time of Senebier and Tessier, and which were the results of erroneous experiments. It was difficult to believe that the most refrangible rays, violet, for instance, which act the most on metallic bodies, as in photometrical operations, should be precisely those which have least effect in decomposing the carbonic-acid gas in plants and have the least effect over the green matter in leaves. Notwithstanding the confirmation of all the experiments made by Doctor Daubeny, when repeated by numerous physicists and by more accurate methods, the old opinions, appearing more probable, still influenced many minds till Prof. Julius Sachs, in a series of very important experiments, again affirmed the truth. It is really the yellow and orange rays that have the most power, and the blue and violet rays the least, in the phenomena of vegetable chemistry, contrary to that which occurs in mineral chemistry, at least in the case of chlorid of silver. The least refrangible rays, such as orange and yellow, have also the twofold and contrary property, such as pertains also to white light, and which produces the green coloring matter of leaves or bleaches them according to its intensity. It is these, also, which change the coloring matter of flowers when it has been dissolved in water or alcohol. Those rays called chemical, such as violet and the invisible rays beyond violet, according to recent experiments confirmatory of those of ancient authors—those of Sebastian Poggioli in 1817 and those of C. M. Guillemin—have but one single well-ascertained effect, that of favoring the bending of the stem toward the quarter from which they come more decidedly than do other rays; yet that is an effect perhaps more negative than positive if the flexure proceeds, as many still believe, from what is going on on the side least exposed to the light.

The effect upon vegetation of the nonvisible calorific rays at the other extremity of the spectrum has been but little studied. According to the experiments we have on this subject, they would appear to have but little power over any of the functions; but it would be worth while to investigate further the calorific regions of the spectrum by employing Doctor Tyndall's process—that is, by means of iodine dissolved in bisulphide of carbon—which permits no trace of visible light to pass.

How interesting it would be to make all these laboratory experiments on a large scale! Instead of looking into small cases or into a small apparatus held in the hand and in which the plants can not well be seen, the observer would himself be inside the apparatus and could arrange the plants as desired. He might observe several species at the same time—plants of all habits, climbing plants, sensi-

tive plants, those with colored foliage, as well as ordinary plants. The experiment might be prolonged as long as desirable, and probably unlooked-for results would occur as to the form or color of the organs, particularly of the leaves.

Permit me to recall on this subject an experiment made in 1853 by Professor von Martins. It will interest horticulturists, now that plants with colored foliage become more and more fashionable. Professor von Martins placed some plants of *Amaranthus tricolor* for two months under glasses of various colors. Under the yellow glass the varied tints of the leaves were all preserved. The red glass rather impeded the development of the leaves and produced at the base of the limb yellow instead of green; in the middle of the upper surface, yellow instead of reddish brown, and below, a red spot instead instead of purplish red. With the blue glasses, which allowed some green and yellow to pass, that which was red or yellow in the leaf had spread, so that there only remained a green border or edge. Under the nearly pure violet glasses the foliage became almost uniformly green. Thus, by means of colored glasses, provided they are not yellow, horticulturists may hope to obtain at least temporary effects as to the coloring of variegated foliage.

The action of electricity on foliage is so doubtful, so difficult to experiment upon, that I dare hardly mention it; but it can easily be understood how a building constructed as proposed might facilitate experiments on this subject. Respecting the action of plants on the surrounding air and the influence of a certain composition of the atmosphere upon vegetation, there would be by these means a large field open for experiments. Nothing would be easier than to create in the experimental hothouse an atmosphere charged with noxious gas and to ascertain the exact degree of its action by day and by night. An atmosphere of carbonic-acid gas might also be created, such as is supposed to have existed in the coal period. Then it would be seen to what extent our present vegetation would take an excess of carbon from the air, and if its general existence was inconvenienced by it. Then it might be ascertained what tribes of plants could bear this condition and what other families could not have existed, supposing that the air had formerly had a very strong proportion of carbonic-acid gas.

In hopes of realizing this idea of a complete botanic laboratory, the author spent his vacation of 1893 in the botanic gardens and greenhouses of Harvard University. On his return to Washington Professor Riley kindly offered him every convenience and space in the insectary of the Department of Agriculture. His 300 experimental plants of wheat and maize were, therefore, brought hither from Cambridge, Mass. But unforeseen difficulties arose, and it is to be hoped that the idea of an experimental laboratory for botanic study may be carried out by abler hands.

Chapter II.

GERMINATION.

INFLUENCE OF UNIFORM TEMPERATURE ON GERMINATION OF SEED.

The results of his own experiments on the germination of seeds at different temperatures were published by De Candolle (1865). His object was to determine the effect of long exposures at low temperatures as compared with short exposures at high temperatures. He eliminated various sources of complication and extended the observations made by Burckhardt (1858). Great pains were taken to keep the seeds at a uniform temperature; the water with which they were wetted was previously brought to the temperature required by the experiment. The first wetting was quite copious. The seeds were first covered with a thin layer of sand and the wettings frequently washed them bare, but no difference was observable in the epoch of germination for naked and covered seeds, showing that the temperatures in the inclosures were very uniform. The thermometers were carefully reduced to a standard Centigrade and their readings are probably correct within a tenth of a degree. The moment of germination is a delicate point to fix and is somewhat arbitrary. The embryo changes within the seed before any change shows itself on the outside. De Candolle takes as the moment of germination that when, the spermoderm being broken, the radicle begins to issue forth. Burckhardt in his experiments took as the epoch of germination the moment when the cotyledons show themselves; but in De Candolle's opinion this is rather an epoch of vegetation than the epoch of germination. It would perhaps be well to consider this phenomenon when we compare the same species under different conditions; but it varies very much from one species to another, since certain plants remain for a long time recurved under the earth or with their cotyledons imprisoned in the remnants of the spermoderm.

The seeds experimented on were as follows:

Cruciferæ	*Lepidium sativum.*
Do	*Sinapis alba.*
Do	*Iberis amara.*
Polemoniaceæ	*Collomia coccinea.*
Linaceæ	*Linum usitatissimum.*
Cucurbitaceæ	*Melon (cantaloupe).*
Ranunculaceæ	*Nigella sativa.*
Pedalineæ	*Sesamum orientale.*
Leguminoseæ	*Trifolium repens.*
Gramineæ	*Zea mays*, var. *precoce.*
Amarantaceæ	*Celosia cristata.*

The conclusions which De Candolle draws from his experiments are as follows:

(A) AT A CONSTANT TEMPERATURE OF 0° C.

From the 7th of March to the 11th of April—that is to say, in 35 days' exposure to this temperature—the following seeds did not germinate at all: *Collomia*, *Lepidium*, *Linum*, *Zea mays*, *Melon*, *Nigella*, *Sesamum*, *Trifolium*, *Celosia*.

The only species which did germinate was *Sinapis*, the various seeds of which germinated in from 11 to 17 days, the latter seemed to De Candolle to be the more proper value of the time.

(B) AT TEMPERATURES FROM 1.4° TO 2.2° C.

Collomia and *Celosia* did not germinate in 35 days; *Lepidium* and *Linum* germinated in 30 and 34 days, respectively, under average temperature of 1,8°. *Zea mays* and *Nigella* did not germinate in 35 days; *Sesamum* did not germinate in 35 days; *Sinapis* germinated in 16 days, at an average temperature of 1.9°.

(C) AT TEMPERATURES VARYING BETWEEN 2.6° AND 3.2° C.

Collomia did not germinate in 36 days; *Lepidium*, about one-half of the seeds germinated, on the twelfth, sixteenth, and thirty-first days, respectively; *Linum* germinated on the seventeenth and eighteenth days, at an average temperature of 3.1°; *Zea mays* did not germinate in 36 days; *Nigella* did not germinate; *Sesamum* did not germinate. Three *Sinapis* seeds germinated on the ninth, one more on the seventeenth day. A new sowing of *Sinapis* gave one seed germinating on the sixth day. Afterwards the temperature was allowed to rise gradually, but the seeds which had not germinated before came to nothing.

(D) AT TEMPERATURES FROM 4.2° TO 6.1° C.

About one-half the *Collomia* seeds germinated on the seventeenth day, at an average temperature of 5.35°; *Lepidium* germinated abundantly on the eighteenth day; *Zea mays* did not germinate; about one-fifth of the *Linum* seeds germinated on the seventeenth day (average temperature 4.8°); *Nigella*, *Sesamum*, and *Sinapis* did not germinate.

Possibly the moisture was too large in series (C) and (D).

(E) AT TEMPERATURES BETWEEN 5.4° AND 6° C.

Some *Collomia* seeds germinated in 14 days; *Lepidium* germinated freely on the fifth day; *Linum* germinated freely on the sixth day; *Zea mays* did not germinate in 36 days; *Nigella* germinated in twenty-seventh day; *Sesamum* did not germinate in 36 days; *Sinapis* germi-

nated abundantly the fourth day; *Iberis* germinated the fourteenth day; *Trifolium* germinated the tenth day; *Melon* did not germinate in 36 days.

(F) TEMPERATURES ABOUT 9.2° C.

Collomia germinated in 6¾ days after sowing; *Lepidium* germinated the third day; *Linum*, 1 seed began to germinate the second day, several others the fourth; *Mays*, 1 seed germinated the tenth day, 2 others the twelfth day, and others afterwards; *Melon* did not germinate; *Nigella* germinated the fifteenth day; *Sesamum* did not germinate; *Sinapis* germinated at the end of 3½ days; *Iberis* germinated the sixth day; some *Trifolium* seeds germinated the fifth day, others the sixth, eighth, etc.

(G) TEMPERATURES FROM 12° TO 13° C.

For the first three days the average temperature of the soil was 12.9°. The individual results were as follows: *Collomia* germinated from the sixth to the seventh day; *Lepidium* germinated after about 1¾ days (in a second experiment at 12.9° C. it germinated in 1¾ days as before); *Linum* germinated in about 2¾ days (in a second experiment at 13.5° it germinated at the end of 1¾ days); 2 *Mays* seeds out of 17 germinated at the end of the fifth day, and half of them had germinated on the seventh day; *Melon* did not germinate during 60 days; a quarter of the *Nigella* seeds germinated the ninth day; *Sesamum* germinated abundantly at the close of the ninth day; *Sinapis* germinated after 1¾ days (in a second experiment it germinated in about 40 hours, the average is 41 hours under a temperature of 12.9° C.); *Iberis* germinated in 3¼ to 4 days; *Trifolium* seeds sprouted unequally at the end of the third day (a second experiment gave 3 hours less than 3 days, or 69 hours, under a temperature of 13°).

(H) TEMPERATURES OF ABOUT 17° C.

Lepidium (mean of two experiments) germinated in 1½ days, under 17.05°; *Linum*, mean of 2 experiments, germinated in 3 days, temperature 17.05° C.; *Trifolium*, 2 experiments, germinated in 2.6 days, temperature 17.05° C.; *Sinapas*, mean of 3 experiments, germinated in 1.7 days, temperature 17.2°; *Collomia*, 1 experiment, under 16.9° germinated in 5½ days; *Mays*, 1 experiment, germinated in 3¾ days, temperature 16.9° C.; *Melon*, 1 experiment, began to germinate in 9¼ days, temperature 16.9°; *Nigella*, 1 experiment, germinated the sixth day, temperature 16.9°; *Sesamum*, 1 experiment, germinated the third day, temperature 16.9°; *Iberis*, 1 experiment, germinated the fourth day, temperature 16.9°.

(I) TEMPERATURES OF ABOUT 20° TO 21° C.

Lepidium germinated in 38 hours under 21.1°; *Linum* germinated in 36 hours under 21.1°; *Mays* began to germinate in 42 hours under 21.1°; *Nigella* germinated in 4¼ days under 21.1°; *Sesamum* germinated in about 33 hours under 21.1°; *Sinapis* germinated in 22 hours on the average under 21.1°; some *Trifolium* seeds germinated in 42 hours under 21.1°; *Iberis* germinated in 2¾ days under 20.4°; only one *Collomia* seed germinated in 15½ days under 19.6°; 2 *Melon* seeds out of 10 germinated in 68 hours under 19.4°.

(K) TEMPERATURES FROM 24° TO 25° C.

Linum germinated in 38 hours under 25.05°; *Mays*, 1 seed in 12 germinated in 23 hours (half the seeds had germinated within 44 hours under 25.05°); *Melon*, 2 seeds in 10 germinated in 44 hours, the others subsequently under 25.05°; *Sesamum* germinated in from 21 to 22½ hours under 25.05° (a second experiment gave 22½ hours under 24.6°); *Sinapis* germinated in about 36 hours under 25.05°; *Trifolium* germinated in 42 hours under 25.05°; *Nigella* and *Iberis* observations accidentally lost; *Lepidium*, 2 seeds in 10 germinated at the end of the sixth day, and the majority of the seeds between the sixth and seventh day under a mean temperature of 23.65°. A repetition gave 38 or 39 hours under a temperature of 21.1°; a third repetition gave 16 hours under a temperature of 26.5°, but which unfortunately ran up to 43° during a few hours. De Candolle concludes that there was some accident or mistake as to the first experiment, and therefore rejects it; probably the wrong seed was sown. He adopts for *Lepidium* 38 hours under 21.1° C. *Collomia* did not germinate until the twenty-seventh day, when 2 seeds sprouted under an average temperature of 21.5°.

(L) TEMPERATURES OF ABOUT 28° C.

Two *Lepidium* seeds germinated in 39 hours, but the greater part not at all in 4 days; *Linum*, 1 seed germinated at the end of 2½ days, 3 seeds by the end of the third day, but the majority not at all; *Mays*, 1 seed germinated in 36 hours, and the majority, with vigor, in 48 hours; *Melon*, 1 seed germinated at the end of the third day, and the majority in 3¼ days; *Sesamum* germination began in 22 hours, and began to be abundant in 25 or 26 hours (a repetition gave 1 seed germinated in 31 hours under a temperature of 27.5° C.); *Sinapis*, 2 seeds out of 10 germinated at the end of the third day, a third seed 6 hours later, and the rest did not germinate; a few *Trifolium* seeds germinated at the end of the third day; *Collomia* and *Nigella* did not germinate in 8 days; a few *Trifolium* and *Linum* seeds germinated in 8 days under a temperature of 34°.

(M) TEMPERATURES FROM 40° TO 41° C.

Two *Sesamum* seeds germinated in 10½ hours under 40.7°, and the others immediately after; 3 *Melon* seeds germinated in 94 hours under 40.6°; none of the other seeds germinated at all in 4 days.

(N) HIGHER TEMPERATURES.

MM. Lefebure (1800) and Edwards and Colin (1834) have shown that most seeds undergo an alteration at a temperature of 50° C., so that they will not germinate after that, even when put under most favorable conditions. Some seeds when kept dry can be warmed in a stove almost to the point of combustion, but in water they lose the power of germination at 55° or 50°, or perhaps lower. In humid soil the seed is altered in proportion to the abundance of the water and the temperature of the soil. Thus, in De Candolle's above-given experiments, the seeds being kept quite wet could lose the power of germinating under 50° and perhaps under 34°, as some of the preceding experiments show, without, however, precisely defining this limit. Therefore De Candolle only experimented on the seeds of *Sesamum* at high temperatures with the following results: The temperature varied from 50° to 57° C. The seeds were watered copiously. One seed in 5 germinated in 25.7 hours at an average temperature of 51.5° C. On repeating the experiment, 3 seeds in 12 germinated at the end of 6 days, and 2 subsequently, but the majority did not germinate, the temperature having averaged 44° C. during the first 26 hours and 20° C. during the remainder.

For ease of study I have collected most of De Candolle's results for each of the eleven plants, respectively, into the following small tables:

Tables showing results of De Candolle's experiments on the germination of seeds at different temperatures.

LEPIDIUM SATIVUM.

Temperature.	Time.	Temperature.	Time.	Temperature.	Time.
°C.		°C.		°C.	
1.8	30 days.	9.2	3 days.	26.5	16 hours.
2.9	12 days.	12.9	1.75 days.	28.0	39 hours.
5.3	18 days.	17.05	1.5 days.		
5.7	5 days.	21.1	38 hours.		

SINAPIS ALBA.

0.0	17 days.	9.2	3.5 days.	25.05	36 hours.
1.9	16 days.	12.9	41 hours.	28.0	72 and 78 hours.
2.9	9 days.	17.2	Do.		
5.7	4 days.	21.1	22 hours.		

IBERIS AMARA.

Temperature.	Time.	Temperature.	Time.	Temperature.	Time.
°C.		°C.		°C.	
5.7	14 days.	12.9	3.6 days.	20.4	2.75 days.
9.2	6 days.	16.9	4 days.		

COLLOMIA COCCINEA.

5.35	17 days.	12.9	6.5 days.	21.5	27 days.
5.7	14 days.	16.9	5.5 days.		
9.2	6.75 days.	19.6	15.5 days.		

LINUM USITATISSIMUM.

1.8	34 days.	9.2	2–4 days.	21.1	36 hours.
3.1	17 days.	12.9	2.75 days.	25.05	38 hours.
4.8	Do.	13.5	1.75 days.	28.0	2½–3 days.
5.7	6 days.	17.05	3 days.	34.0	8 days.

MELON (CANTALOUPE).

16.9	9.25 days.	25.05	44 hours.	40.6	94 hours.
19.4	68 hours.	28.0	3.1 days.		

NIGELLA SATIVA.

5.7	27 days.	12.9	9 days.	21.1	4.25 days.
9.2	15 days.	16.9	6 days.		

SESAMUM ORIENTALE.

12.9	9 days.	25.05	21–22½ hrs.	27.5	31 hours.
16.9	3 days.	24.6	22½ hours.	40.7	10½ hours.
21.1	33 hours.	28.0	22–26 hours.	51.5	25.7 hours.

TRIFOLIUM REPENS.

5.7	10 days.	13.0	69 hours.	25.05	42 hours.
9.2	5–6 days.	17.05	2.6 days.	28.0	72 hours.
12.9	72 hours.	21.1	42 hours.	34.0	8 days.

ZEA MAYS.

9.2	10–12 days.	21.1	42 hours.	28.0	36 and 48 hours.
12.9	5–7 days.	25.05	23–44 hours.		
16.9	3.75 days.				

De Candolle's general conclusions are as follows:

(1) Contrary to the opinions of early investigators, such as De Seynes (1863) and Edwards and Colin (1834), it is now proven that some seeds, and probably others, do germinate in water at the temperature of 0° C.

(2) There is a minimum temperature at which each species germinates. These temperatures are as follows:

Sinapis alba germinates at 0° C., and possibly below this temperature if the water can be kept liquid.

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Lepidium and *Linum* did not germinate at 0° C., but did germinate at 1.8° C.

Collomia did not germinate at 3° C., but did germinate at 5.3° C.

Nigella, *Iberis*, and *Trifolium repens* did not germinate at 5.3° C., but did germinate at 5.7° C.

Mays did not germinate at 5.7° C., but did germinate at 9° C.

Sesamum did not germinate at 9° C., but did germinate at 13° C.

Melon did not germinate at 13° C., but did germinate at 17° C.

Malvaceæ, *Gossypium herbaceum;* variety not specified: Some cotton seeds on which experiments had been made two years before would not then germinate, but did germinate at this time at 40° C.

Raphanus sativus (radish): Lefebure had shown that these seeds germinate at 5° or 6° C. as their minimum temperature.

Triticum (winter wheat), *Hordeum* (barley), *Secale cereale* (rye): All of these Gramineæ germinated at 7° C., according to Edwards and Colin, but this is probably not their minimum, for certainly barley will germinate at a lower temperature by prolonging the experiments.

We conclude, therefore, that each species has a minimum temperature at which it germinates, and the ordinary experience of the farmer would suggest this, but in his work one can hardly decide whether seeds sown too early in the springtime are simply retarded by specific low temperatures or whether germination is quite impossible. These present experiments show that if the temperature is too low, then germination is prevented. In calculations on the relation of temperature to vegetation one must consider only facts deduced from prolonged, constant temperatures. In the study of growth under natural conditions one must consider certain temperatures as useless and ineffective as concerns the germination of certain species of plants. There are, moreover, other facts that show that the same rule holds good for leafing, flowering, and maturing.

According to De Candolle's experiments, the species that require high temperatures as minima for germination are all from warm countries. Such species can not flourish in cold countries, for if they do germinate there this happens too late in the springtime and they can not ripen their fruits before winter. Among the species which germinate at low temperatures there are some that can exist in temperate climates, but these do not extend very far toward polar regions, either for reasons foreign to the germination or else because, having germinated too early, the delicate shoots are killed by frost.

(3) There is for each seed a maximum temperature beyond which germination is impossible. The above experiments determine such maxima approximately as follows:

Nigella does not germinate if the mean temperature exceeds 28° C.

Collomia does not germinate if the mean temperature exceeds 28° C.

Trifolium repens: Very few seeds germinate at 28° C., and probably none at 30° C.

Mays: Probably the upper limit is 35° C., although one seed germinated after being exposed to 50° C.

Melon will stand 40° C., but it is probable that above 42° C. germination is impossible.

Sesamum will stand 40° C., and possibly 45° C., the latter being the upper limit.

These upper limits, as I have before said, depend very much on the moisture, and on account of the difficulty of the experiment I have not endeavored to obtain great exactness.

Lepidium and *Linum:* According to the experiments of Burckhardt, some of these seeds have germinated after an immersion of half an hour in water at 50° C., but not after half an hour in water at 60° C.

Raphanus sativus (radish): Lefebure shows that these seeds germinate in moist earth at a maximum temperature of 38° C.

Triticum (winter wheat), *Triticum* (spring wheat), *Hordeum* (barley), *Secale cereale* (rye), and *Avena* (oats) germinate perfectly at 40° C., partially at 45° C., and not at all at 50° C.

(4) The range between the maximum and minimum temperatures at which germination is possible differs appreciably for these various species. Evidently a small range is a condition unfavorable to an extensive geographical distribution.

(5) Marked differences are observable between seeds of the same species and coming from the same place. This is well known to the farmer and strongly affected some of the preceding observations. The seeds of the same plant or the same capsule are not identical physically nor chemically. But if the temperature and moisture are those most favorable to germination, many seeds will sprout simultaneously, whereas near the maximum, and especially the minimum, temperature the seeds germinate very irregularly and many of them not at all.

(6) The structure of the seeds, especially the presence and nature of the albumen within them, ought to exert a definite influence, but the small number of species that De Candolle experimented upon does not allow of extensive generalizations.

The species having little or no albumen—viz, *Sinapis*, *Lepidium*, and *Linum*—germinate at very low temperatures. Those having the next larger amounts of albumen—viz, *Nigella*, *Collomia*, and *Zea mays*—germinate at about 5° C.; but *Sesamum*, which has but little albumen, requires 10° or 12° C.

At 17° or 18° C. all these seeds germinate well, but the length of time required increases somewhat as the albumen increases, showing that the latter exerts a retarding influence. The order of germina-

tion at this temperature is as follows: *Lepidium*, 1.5 days; *Sinapis*, 1.7 days; *Trifolium*, 2.6 days; *Sesamum*, 3 days; *Linum*, 3 days; *Iberis*, 4 days; *Zea mays*, 3.75 days; *Collomia*, 5.5 days; *Nigella*, 6 days; *Melon*, 9.25 days.

(7) The relation between temperature and the time required for germination is such that the time is shortest at a certain best temperature for each seed, and increases to infinity or impossibility as we depart from that temperature toward the maximum and minimum limiting temperatures. All calculations of the sums of daily temperatures, both in geographical botany, in agriculture, and horticulture, are complicated by hypotheses and affected by many causes of inaccuracy, so that De Candolle hesitates to draw very precise conclusions from his laborious experiments. However, he shows that if the duration required for germination as expressed in days is multiplied by the corresponding temperature expressed in degrees Centigrade we shall then obtain much more consistent figures if the temperatures are counted from the minimum for each plant instead of from the zero of the Centigrade thermometer. The tables on pages 32 and 33 give the temperatures and the durations in days, as observed by De Candolle for the species experimented upon by him. For three of these he adopts as the starting point of his calculations the following minimum temperatures—viz, for *Lepidium*, 1° C.; for *Trifolium repens*, 5.5° C.; for *Sesamum*, 11° C.

(8) When seeds are subject to variable temperatures, as occurs to a slight degree in these experiments, and to a still larger degree in nature, the so-called useless or ineffective temperatures may be in fact unfavorable and even retard the germination, since moisture continues to be absorbed into the seed, although the latter can make no use of it.

(9) There is some analogy between the germination of seeds and the hatching of eggs. Thus Millet and Robinet have shown that the hatching of the eggs of the silk worm requires at least a temperature of 9° C., and that as the temperature increases above this the number of days required to hatch diminishes faster than required by a constant sum total, so that at a temperature of 20° C., ten days accomplishes more than twenty days will do at a temperature of 10°. This shows an influence of the minimum temperature similar to that for the seeds of plants.

An entirely analogous case has been worked out by the author with regard to the hatching of the eggs of the grasshopper when deposited in the soil of our western plains. The details of this study will be found in the First and Second Reports of the United States Entomological Commission, and afford an illustration of the possibility of making from meteorological data a prediction as to the hatching

of the eggs of this pest, such as may guide the farmer in his sowing or planting so that the young plant may escape the ravages of the young insects.

INFLUENCE OF TEMPERATURE AND MOISTURE ON GERMINATION.

The influence of temperature and moisture on the sprouting of seeds has been studied by Sturtevant at Cornell University (Agr. Exp. Sta., Bull. No. 7), with results generally confirming those of De Candolle. Sprouting occurs better with a uniform than with a variable temperature, so that the method of Quetelet, which requires us to take account of the squares of the temperatures, is no better than that which considers the simple temperature. The rapidity of sprouting diminishes with the decrease of temperature. The percentage of seeds that sprout does not depend upon the uniformity of the temperature. Sprouting takes place more rapidly in a rather dry soil, but a decidedly wet soil is injurious. By soaking the seed before planting it, the interval between planting and sprouting is diminished, but not between soaking and sprouting; hence the total time required and the total percentage of sprouting seeds is not much affected by the soaking. The exposure to light during germination retards some seeds, but does not affect others. Actual planting in the field may give 50 per cent less germinations than given by similar seeds planted in experimental pots under control.

INFLUENCE OF LIGHT AND HEAT ON GERMINATION.

Pauchon (1880) summarizes the results of the studies of many authors on the relative influence of light and heat on the germination of seeds and the growth of plants. The following section is condensed from him:

Edwards and Colin (1834) state that in their day little was known as to the influence of light and air on the green matter and on the respiration of plants; since then, however, it may be considered as established that the life of a plant varies in proportion to the adaptation of the plant to its surroundings. The study of the influence of light may be said to have begun with Lavoisier, who thought that the light directly combined with certain parts of the plant producing the green leaves and colored flowers, and that without light there could be no life. Similarly Moleschott (1856), at Zurich, affirms that in general everything that breathes or moves draws its life from the light of the sun.

Boussingault (1876), controverting a statement of Pasteur, maintains that the growth of mushrooms and mold in the dark is not an exception but a confirmation of the general rule, and that if the solar

light should be cut off both the plants having chlorophyl, and also the plants that do not have it, would disappear from the surface of the globe.

Berthelot, in his essay on the mechanics of chemistry as based on thermochemistry, shows that the action of the light is demonstrated by the formation of complex chemical effects, isomeric changes, and more complex reactions. For instance, the combination of free oxygen is stimulated in a great many cases by the action of light, as is shown by the bleaching of fabrics of any kind exposed to the air and by the oxidation of volatile oils. All the oxidizing in reactions brought about by the action of light is exothermic—that is to say, there is a loss of energy in the transition from the compound body to its elementary components and a disengagement of heat. The light plays the rôle of a determining agent. On the other hand, when a complex body is built up in the cells of a plant, by drawing in elementary bodies from the atmosphere and soil, the reaction is endothermic, and solar heat is absorbed and rendered latent in the plant.

Sachs, Wiesner, and Mikosh would seem to have established the principle that the formation of the green matter of a plant is not dependent wholly on the light as such, but also demands a certain temperature, varying between 0° and 35° C., for the various plants of Europe. They show also that an increase in the temperature of the atmosphere, with equal increase of light, increases the rapidity of the formation of the chlorophyl up to a certain maximum temperature, and that in proportion as the temperature departs from this favorable maximum, either above or below, the formation of the green matter becomes less and less active, until when the limits 0° or 35° C. are exceeded it ceases altogether. But the temperature most favorable for the formation of chlorophyl under the action of light has but little connection with the temperature that promotes the further action of the chlorophyl after it has been formed within the plant. Thus Timiriazeff (1880) shows that the activity of the chlorophyl consists in the absorption of certain radiations; but in order that these radiations may act it does not suffice merely that they should be absorbed; it is further necessary that there should be a very considerable intensity of heat, in order to furnish to the chlorophyl the definite number of calories necessary for the decomposition of the carbonic-acid gas taken in from the atmosphere.

In general, under ordinary conditions light is indispensable to the formation of chlorophyl. To this general law there are a few apparent exceptions, as follows: The embryos of the genera *Pinus* and *Thuya* have their cotyledons colored an intense green at the moment of germination, even when they have been or appear to have been completely deprived of the action of light. So also with a certain number of phanerogams in which the embryo is protected by thick

integuments; finally, the fronds of certain ferns have a green color, even when they grow in complete darkness. With regard to the seeds of *Acer*, *Astragalus*, *Celtis*, and *Raphanus*, it has been shown by J. Böhm that when they germinate in darkness they do not acquire any green color; Flahault (1879) has obtained the same result for the seeds of the *Viola tricolor*, the *Acer pseudoplatanus*, and the *Geranium lucidum*. Similarly as to the other seeds above enumerated the studies of Sachs and Flahault render it probable that in most cases there was stored up in the seed certain reserve nutrition, which reserve, originally formed under the action of light, can subsequently in the act of germination temporarily replace the further direct action of light. It would thus seem that in no case can dark heat truly replace the action of sunlight.

On the other hand, light can replace heat in the process of vegetation. This was first shown by De Candolle, and a striking illustration is quoted by Moleschott (1856), who shows that by the influence of light during the resplendent nights of the polar regions the harvests ripen in a short time, while many days of our autumn heats in lower latitudes scarcely suffice. It is the quantity of light and the quality of the radiations that these plants receive that enable certain cereals, such as barley and oats, to be cultivated as far north as 70° of latitude. The observations of Schleiden on the potato, of De Candolle on the radiola, and of Haberlandt (1866) on oats, show that there exist decided differences in the quantities of heat necessary to the development of different species of vegetables under different latitudes, and that the most important cause of these differences is the quantity of light which these plants receive. De Candolle, in his botanical geography, says the effect of light is shown in the northern limits of certain species; thus the radiola is perfected by a total supply of heat represented by 2,225 day-degrees in the Orkneys at 59° north, but by a total of 1,990 day-degrees at Drontheim, latitude north 63° 25′; the difference (235) corresponds to the fact that the longest day is 1¼ hours longer at Drontheim than in the Orkneys, which increased sunlight enables the plant to complete its growth better under the same temperature.

Wheat furnishes a still more striking example. It begins to vegetate when the temperature in the shade is about 6° C., and observation has shown that it requires the following day-degrees to ripen: At Paris in 138 days, total shade temperature 1,970° C.; at Orange, 117 days, total shade temperature 1,601° C.; at Upsala, 122 days, total shade temperature 1,546° C.; at Lynden (North Cape), 72 days, total shade temperature 675° C. Or, if we use, not the shade temperatures, but those of a thermometer exposed to the full sunshine, as is done by Gasparin, then the above figures become at Orange, 2,468 day-degrees; Paris, 2,433 day-degrees; Lynden, 1,582 day-degrees.

These remarks of De Candolle with reference to germination are equally applicable to the whole period of growth of the plant.

As to the method of calculating the sum total of temperatures De Candolle found that it may be conducted in two ways, either by adding together all the mean daily temperatures above 0° C. or by omitting the useless degrees and adding all the others. This last method would seem to be the most logical, but can rarely be employed, owing to our ignorance of that minimum temperature below which all must be omitted. On the other hand, if we consider that a plant which vegetates between 10° C. and 30° C. has a maximum at 20° C., and if we seek the coefficients of growth corresponding to each successive degree of temperature, we find, as Boussingault has shown, that these coefficients vary for each degree as we depart above or below the temperature most favorable to vegetation.

Similarly De Candolle (1865) has shown that near the minimum and near the maximum temperatures the rate of germination is more difficult, and therefore slower, than at the intermediate or best temperatures; consequently, both in germination and in subsequent vegetation, it is necessary to recognize the fact that calculations of the sums of heat in connection with the study of the geographical distribution of plants are complicated with hypotheses and many sources of error.

Schuebeler (1862) shows that cultivated plants in northern countries have more highly colored flowers, larger and greener leaves, and larger seeds, which are more highly colored and richer in essential oils, than those of southern regions. Bonnier and Flahault (1878) have shown the same facts for uncultivated plants. Both these authors attribute this result to the prolonged action of sunlight, and the latter shows that the variations are exactly proportional to the duration of sunlight. In Flahault's more recent observations he shows that there must necessarily exist a relation between the quantity of carbonic acid decomposed and the quantity of carbonaceous matters formed by the plant, and that in general the sunlight has a very remarkable influence on vegetation since it compensates in a large measure for the deficiency of temperature.

It is, furthermore, to this influence of light that Pauchon attributes the singular fact that plants cultivated in high latitudes are endowed with a vegetating power greater than that of southern countries, so that when transported to the south their seeds ripen sooner than those of the southern plants. This subject has been especially studied by Tisserand in his memoir on vegetation in high latitudes, as cited by Grandeau in his work on nutrition of plants. According to Tisserand a plant behaves in northern latitudes as a more highly perfected machine and one that performs better than southern plants. In regions where it has neither time nor heat it gains in activity and

in the speed with which it perfects its own growth. It seems to Pauchon that we may properly interpret this phenomenon if we admit that a seed transported from the north to the south finds itself in climatic conditions more favorable to the development of the embryo which it contains and of the plant which is to follow. What the action of light loses in duration in proportion as we move toward the equator it gains in intensity. It may be that the cause of this increased activity is due to the larger size of the northern seeds or to their greater richness in the essential oils. Pauchon thinks that the embryo of such a seed should not be compared to a more perfect machine; it is rather an identical machine, but better nourished by the reserve of combustible and nutritive material in the perisperm. Possibly the abundance of essential oils contained within the seed contributes to furnish to the embryo in northern countries the materials for the oxidation that is necessary in order to maintain its temperature during germination and to struggle against the severity of the climate.

Tisserand (1876) has shown that the rye cultivated in northern Norway has not the same chemical composition as that of France and Algeria, and that in general, as we go northward, or as we rise above the level of the sea, or as the temperature lowers without diminishing the quantity of light, we see the starch in the grain increase relatively to the nitrogenous components. Wheat grown at Lynden (North Cape) has a smaller proportion of gluten than the wheat of France, and the latter less than the wheat of Africa. On the other hand, barley raised at Alten, on being sown at Vincennes on the 7th of April by Tisserand, was ripe on the 18th of June, or thirty-seven days in advance of French barley, so that in order to mature it required a sum total of heat far less than the French barley. The reverse is true when southern grains are carried north and sown in colder climates. Therefore, as Marie-Davy has remarked, plants become acclimated more or less rapidly according to their own nature and the extent of the climatic variations that are imposed upon them; the climate produces in them a functional change which corresponds to an organic change the nature of which often escapes our observation. It is therefore not necessary that each phase of vegetation should correspond to a constant sum of heat in very different climates. That which it is important for us to know is what are the limits between which this sum total can vary, for the same species of plant under different climates.

The general fact that the quantity of nitrogen contained in the seeds increases as we approach the warmer climates leads to the hypothesis that the formation of albuminous reserves within the seed takes place in proportion to the temperature, and that the formation of starch and other reserves takes place in proportion to the duration

of the light and the action of the chlorophyl of the leaves. As we pass from the pole to the equator the luminous intensity of the sun-light increases from a hundred to a thousand, but its duration diminishes during the growing season from a hundred at the poles to fifty at the equator. Among the special investigations into the action of sunlight we note that of Timiriazeff (1877), who has shown that a very intense light, after traversing a certain thickness of green-leaf cells, has no further action on the phenomena of the reduction or decomposition of carbonic-acid gas; in other words, it acts the same as darkness would do. On the other hand, Paul Bert, by exposing plants to the action of light which had been sifted through a solution of chlorophyl, invariably found that the development of the green matter of the leaf was completely arrested; inversely, he found the green matter produced to its normal amount when the plant received only light that had been filtered through a solution of iodine in bisulphide of carbon, which solution, as we know, cuts off all visible rays, but allows the red and infra-red to pass through with great freedom. This would seem to demonstrate that chlorophyl is formed by the action of the red portion of the spectrum.

As to the effect of light on the germination of seeds, Pauchon (1880) gives a critical summary of views by different authors, from which we condense the following:

Miesse (1775), from observation on the Camelina (*Myagrum sativum*), concludes that the seeds grow in darkness the same as in full daylight, and that light does not seem to influence this stage of vegetation.

Sénébier (1782), from observations on seeds of lettuce and beans, some of which were exposed to the full sunlight, others to sunlight after filtering through a thickness of water, others in the dark, and others in red, violet, and yellow light, respectively, reached the conclusion that light was injurious; but his results were not decisive, because of his neglect to observe exactly the temperatures under different conditions.

Ingenhousz (1787) exposed an equal number of mustard seeds in places receiving different amounts of light. He himself concluded that the light of the sun is as injurious to vegetation at the beginning of its life as it is advantageous to vegetation in the fullness of its life. But a more careful consideration of Ingenhousz's experiments shows that the moisture and the temperature in his several localities varied so much as to prevent any serious conclusion as to the action of light itself.

Bertholon (1789), in an article on the effect of electricity, shows

that up to that time it had not been proven whether the germination of the seeds was affected by light or by humidity. His own experiments convinced him that the latter was more important.

Sénébier (1800) made additional experiments on peas and beans, sowing them in sponges, which were kept equally moist, all inclosed under glass covers, so that no evaporation could take place. Some were exposed to sunlight and some were kept in the dark, but those which were in the dark germinated much sooner than those in the light. But in such experiments as these the sources of error are numerous, and the fact that there was no renewal of the air under these covers was especially unfavorable to germination. In fact, Leclerc (1875) has shown that under the influence of mercurial vapor, as it existed in Sénébier's experiments, a large portion of seeds are killed, so that with our present knowledge we can not accept Sénébier's conclusions.

Lefébure (1800), having finally accepted the conclusions of Sénébier and Ingenhousz relative to the injurious influence of light on germination, repeated the experiments, but also observed the temperatures more carefully, and in addition sought to determine the effect of light that had passed through plates of white, green, black, red, and blue glass; but he added little to our knowledge, although he himself concluded that the seeds under white glass were retarded.

Th. de Saussure (1804) endeavored to ascertain whether the influence observed by others was due to light or heat, and he concluded that nothing demonstrates that light has an injurious influence independent of the heat that accompanies it.

Keith (1816) made no observations himself, but controverted the conclusions of De Saussure.

Boitard (1829) sowed the auricula seeds in three flower pots, but the conditions as to temperature and moisture are not sufficiently known to justify us in drawing any conclusion.

A. P. de Candolle (1832) says:

> I do not deny that darkness may be useful in germination, but I do deny that it is necessary to think that light has no action on germination. Analogy indicates this, theory confirms it, and experience demonstrates it.

According to De Candolle, light favors the decomposition of carbonic acid, but germination demands the formation of carbonic acid; therefore darkness will favor germination. This theory thus enunciated by De Candolle has been accepted by many authors without proper experimental basis.

Ch. Morren (1832) experimented upon water cresses grown under different colored glasses. He concluded that as darkness favored germination, so the individual colors of the spectrum, acting each by itself, have a special influence that favors germination in such a way that

those colors that have the greatest illuminating power are those that least favor germination.

Ad. Brongniart (1832) announced as the results of his experiments that the retarding influence of light depends not only on the illuminating power of the colored light, but on the relative quantity of white light that passes through the different colored glasses. In all these experiments the seeds were several millimeters below the surface of the soil, so that the colored lights did not affect the seeds directly, but indirectly through the soil whose temperature and moisture and evaporation may easily be of predominating importance.

Ph. A. Pieper (1834), Meyen (1837), Zantedeschi (1846), and Belhomme (1854) have all experimented on the growth of seeds under colored glasses; but the sources of error incident to this method of observation prevent us from drawing any conclusion as to the influence of light itself.

Ville (1865) says that the injurious effect of solar radiation on germination is the result of the heat only and that the effect of the light is inappreciable. For aquatic plants whose seeds germinate in the water, darkness seems decidedly favorable to germination, but it acts only in an indirect manner by preventing the warming of the water and the disengagement of the oxygen that is dissolved in this water.

Charles Darwin (1877) says that certain species of seeds do not grow well when they are exposed to the light, even the diffuse light of a room.

Duchartre (1877) considers the action of darkness as a secondary influence, useful but not at all essential and concerning which there has been too much exaggeration.

Faivre (1879) has shown that the appearance of the primordial latex occurs at a moment when the radicle is only a few millimeters long and when the cotyledons are still inclosed in the seed envelopes and have not yet received the action of light. He notes that under a yellow light obtained by transmitting sunlight through a solution of bichromate of potash the seeds develop their chlorophyl and their latex more rapidly, and consequently have a shorter period of germination than under a blue light obtained by transmitting sunlight through a solution of the ammoniacal oxide of copper.

Detmer (1880) has consecrated an extensive work to the study of the germination of seeds, and states that concerning the action of light we are still ignorant as to whether it is direct—that is to say, whether it stimulates the storing up of new substances in the vegetable tissue or whether, on the contrary, it strengthens the persistence within the cells of some special process having a more or less intimate relation to the phenomena of growth and which can only

proceed in darkness. Detmer adds a few historical references, viz, Humboldt (1794), according to whom seeds sprout more easily in darkness than in light; Fleischer (1851), Heiden (1859), and Nobbe (who all consider solar rays as having no action on the seeds), and, finally, Hunt (1851), who considers that light retards germination.

After this preliminary historical survey, Pauchon communicates the results of his own experiments as to the influence of light on germination on the following twenty-two species of plants:

Cruciferæ:
- Brassica napus.
- Iberis amara.
- Lepidium sativum.
- Sinapis alba.
- Raphanus sativus.

Ranunculaceæ:
- Delphinium Consolida.
- Nigella sativa.

Cucurbitaceæ:
- Cucurbita melo var. melon vert.

Papaveraceæ:
- Papaver somniferum.

Euphorbiaceæ:
- Ricinus communis.

Gramineæ:
- Zea mays.

Leguminoseæ:
- Arachis hypogæa.
- Dolichos lablab.

Rubiaceæ:
- Coffea arabica var. Rio.
- Spilanthes fusea.
- Helianthus annuus.
- Carthamus tinctorius.

Malvaceæ:
- Hibiscus esculentus.

Polygonaceæ:
- Fagopyrum esculentum.

Linaceæ:
- Linum usitatissimum.

Bignoniaceæ or Pedaliaceæ:
- Sesamum orientale.

Liliaceæ:
- Pancratium maritimum.

After deducting doubtful results or failures Pauchon gives the following conclusions (see p. 131 of his work above quoted):

(1) In 22 experiments germination occurred first in the light; in 26 experiments it occurred first in the dark.

(2) Five times we obtained duplicate results favorable to the light for the same species of plants (*Arachis*, *Zea mays*, *Dolichos*, *Sinapis*, and *Linum*). Eight times these duplicate results were favorable to specimens kept in the dark (*Helianthus*, *Delphinium*, *Pancratium*, *Ricinus*, and *Papaver*). In one case (*Linum*) two results were obtained favoring light and two favoring darkness.

(3) Among the 22 species of plants used in the experiments 14 gave mixed results equally favorable whether placed in the light or the dark.

(4) Among the 8 other varieties only 1 gave negative results (*Coffea*); 3 gave results favorable to light (*Cucurbita*, *Spilanthes*, and *Carthamus*); 4 gave results favorable to darkness (*Delphinium*, *Pancratium*, *Lepidium*, and *Nigella*).

It appeared to Pauchon impossible to draw any conclusion whatever from these facts. Should we be astonished at this? The problem is certainly much more complex than appears at first sight.

There is every reason to suppose, for example, that the action of light is not the same under all the conditions of temperature which obtained during these experiments. Here again, however. we are confronted by the unknown; because, in order to draw from these researches the consequences which might flow from them it would be necessary to know precisely the thermic conditions favorable to the germination of each species. Unfortunately this is a very important gap to be still filled up, as the work accomplished in this direction gives only approximate results limited to a very small number of different kinds of seeds. On the other hand, looking to facts of another order, mentioned further on in this work, we think that we may be allowed to suppose that the influence of light can only be favorable to germination when it acts at temperatures below that which is most favorable to germination. A considerable number of observations already cited would seem to be in accord with this view of the subject. But unfortunately the many contradictions that we observed in our results do not allow us to accept this opinion as based upon a solid foundation.

Pauchon then goes on as follows:

Another reason, however, induces me to admit, only with many reserves, the results of experiments whose critical epoch is the visible development of the embryo. A method based on this special observation does not appear to me capable of furnishing a really scientific basis for the determination of the question before us. The process of germination is not, in reality, as simple a phenomenon as the greater number of botanists, perhaps too easily, take for granted. Its complexity is even so great that one can not judge of the actual development of the germ of the plant and of the degree of its physiological activity by the external characters observable by the eye, such as the bursting of the spermoderm and the more or less rapid protrusion of the radicle. I do not hesitate to say, according to observations frequently repeated, that this is an empirical process and entirely deceptive in the particular case that we are dealing with. Although it may be capable of furnishing valuable results when we wish to judge of the influence of some one of the fundamental conditions of germination, it becomes utterly insufficient when it is a question of observing the more delicate and fugitive influences, such as that of light. I have, in fact, in the course of chemical researches, given in the next chapter, demonstrated that for the same stage of apparent development the absorption of oxygen by the seeds in the process of germination varies to a large extent with the temperature, and has no relation to the external growth of the embryo. It is, however, not surprising that the development of the embryo continues in the interior of the seed for a much longer time in one seed than in another of identical appearance; the unknown and variable relation between the reserved nutrition and the rudimentary vegetable is probably the explanation of these hitherto unexplained peculiarities.

Although the researches given in this chapter do not give any positive result on the subject of my work, I have preserved them and pub-

lish them here in order to explain to observers the defects of an experimental process to which, in the future, they would themselves have been tempted to resort; this, moreover, seems to me the more useful in that up to this time this danger does not seem to have struck the attention of botanists. On the other hand, my observations contain some new data relative to the temperatures favorable for the germination of certain exotic seeds.

In consequence of the conclusions to which we have thus been led, it would be useless to study the action of the different portions of the solar spectrum on the apparent progress of germination. How, in fact, can we suppose, in view of the contradictory results already obtained for the condition of light and of darkness—that is to say, for the most extreme conditions—that the employment of the same method can reveal a difference of action for the various portions of the spectrum?

Is it then necessary, after this first fruitless attempt, to give up the solution of the problem, or shall we seek it by another and better method? It is this latter alternative that I have adopted in that I have taken for the basis of a new series of observtions the variations of a physiological process that, in an almost mathematical manner, measures the germinal activity of the vegetable embryo, namely, the respiration.

After giving the details of his experiments on respiration of plants, Pauchon draws the following conclusions (p. 166):

The laws brought prominently forward by the results of these experiments are:

(1) Light exercises a constant and more or less marked accelerating influence upon the absorption of oxygen by seeds in the process of germination. All the experiments made in a strong light have not, however, the same value in demonstrating this fact. But if we have doubts about the precision of the results furnished by experiments in which germination did not invariably take place (and we believe that we have shown by some preparatory experiments that these results have at least a relative value), this certainly is not the case with experiments Nos. 2 and 8, in which all the seeds did germinate. Thus experiment No. 2 showed in favor of light a result as to the oxygen absorbed twice as great as that given by the seeds placed in the dark. In the same way in experiment No. 8 this superiority reaches to one-third of the quantity of oxygen absorbed by the seeds placed in the dark. Finally, the other experiments, and particularly those classed under Nos. 3, 6, and 7, further confirm the generality of this action of light, which we will, besides, find again in a second series of experiments reported hereafter, several of which have shown unanimity of germination in both cases.

(2) There exists a relation between the degree of light and the quantity of oxygen absorbed. Thus, in a diffuse light this accelerating influence shows itself in a most marked manner when the sky is very clear, and the solar radiation reaches us in its greatest intensity. Such was the case in experiments Nos. 2 and 8. Whenever the sky is cloudy this action is more and more weakened and ceases altogether when the sun is completely veiled, as in stormy weather, so that there is a semiobscurity.

However, in all the experiments where the final result has been favorable to the action of light I have convinced myself that a cloudy sky for twelve hours always showed itself in the amount of the absorption of oxygen in such a manner that the examination of these figures, noted day by day, would almost serve to show the state of the atmosphere during the day which preceded the observation. A very conclusive instance of this action is given us by experiment No. 4 of the second series, in which the state of the sky being carefully observed it showed very marked changes.

(3) The accelerating influence exercised upon seeds exposed to the action of light during the day did not stop at night; it continued to act in the dark with an equal, sometimes even with a greater intensity. I will cite as examples experiments Nos. 3, 4, 6, 7, and 8, when observations made twice a day, morning and evening, allowed of examining the fact I state. How can we explain this persistent action of light? One hypothesis only can be admitted. A portion of the action of the light absorbed by the grain during the day is stored up by it and used by it at night to accelerate its respiration. The proof of this is that the differences of elevation [or quantities of absorbed oxygen] shown in the morning by the instruments for seeds kept in the dark are always below those shown by the instruments and plants in the light. The influence of the light, then, continues for a certain time, at least several hours, even after the light itself has ceased to act; on the other hand, however, this action is not exerted immediately. There is one other phenomenon that we have demonstrated by our experiments. Suppose the sky to be very clear; the differences in favor of light are only apparent after two or three days and become much more marked toward the end of the experiment; that is to say, in proportion as the daily action of sunlight is more and more frequently repeated.

(4) I should also call attention to still another peculiarity, viz, that the differences in the quantities of oxygen absorbed in the dark and in the light were generally much greater at the beginning of these researches than in the later experiments, and particularly in those of the second series. The temperature appears to me to be the only element that varied in these experiments. There must therefore be a more intense respiratory action exercised by light at low temperatures, and this influence would become weakened at high temperatures. This fact would be in entire agreement with the demands of physiology. It is easy of comprehension that a scarcity of heat should be counterbalanced by the action of light, which furnishes for the reaction of the respiratory organs the force that they could not obtain from an insufficient temperature. On the contrary, when the heat is intense the intervention of the light is no longer necessary, the first cause being sufficient to excite the process of germination in the protoplasm of the seeds.

(5) This action of light seems to differ a little according as it acts upon seeds containing albumen or those without albumen. In the case of the albuminous seeds of the castor-oil plant the advantage was much more apparent in favor of those exposed to the light, which advantage appeared to me much less decided for the seeds without albumen, such as the haricot bean. Nevertheless, as the experiments were not invariable in their results, the cause of the variations ob-

served can also be accounted for by attributing them to certain differences in the atmospheric conditions.

(6) The more considerable absorption of oxygen by seeds under the influence of light explains the fact that asparagine (the medium for the conveyance of the reserved albuminous substances in the germination of leguminous plants) only disappears in plants exposed to the light and continues present in those raised in the dark. The comparative researches of Pfeffer (1872) upon the chemical composition of asparagine and other substances showed that asparagine is poorer in carbon and in hydrogen and richer in oxygen than legumine and other albuminoids. The transformation of legumine into asparagine is accompanied by the absorption of a certain quantity of oxygen. On the other hand, it is effected only by the influence of light, the reason being that light increases the quantity of oxygen absorbed, and therefore exerts only an indirect influence on this change, as had already been surmised even when we were not acquainted with the reasons.

(7) Other new and important conclusions become apparent from these experiments and those which follow, and although they have no direct connection with the subject of my work I think it will be well to designate them briefly.

The quantity of oxygen absorbed in a certain space of time by a seed in process of germination varies very considerably according to the temperature; it increases with it, as has been already proved in treating of the respiration of plants in the dark. The general results of my experiments, and particularly of Nos. 9 and 10, leave no doubt of this fact. We can therefore easily understand what errors have been committed by those experimentalists who have given calculations of this absorption of oxygen by certain seeds without taking into consideration the conditions as to temperature. Their figures have no value whatever, particularly in view of a fact stated by me several times already, viz, that the quantity of oxygen absorbed by a seed is not at all in proportion to its apparent development, but, on the contrary, undergoes considerable variation, depending upon the influence of the external agents affecting the phenomenon. According to my observations, this quantity may vary as two to one, or even more, in two plants of identically the same weight, but placed in different thermic conditions from the commencement of their germination to the emerging of the rootlet. From this point of view, then, the plant acts like a complete organism, its respiratory action being accelerated or retarded always, however, within physiological limits, like those of an animal under the influence of certain exterior changes.

Having thus shown that germinating seeds absorb more oxygen in the light than in darkness, Pauchon conducted some experiments to determine the ratio between the oxygen and the carbonic acid, and draws the following conclusions (see page 182 of his work):

Experiments Nos. 3 and 4 have a real value for the solution of the problem brought forward in this part of my work. As to the partial results given by experiments Nos. 1, 2, and 5, their accuracy can not be doubted; therefore I shall make use of them as confirmatory documents. I must repeat that the numbers used for the proportions of

carbonic acid are a little smaller than they should be in reality, in consequence of peculiarities inherent to the method and already explained; but as this diminution, which is almost insignificant, is equally present in all the quantities, the result is that the numerical quantities are always comparable, although the ratio may be diminished in an inappreciable degree. Finally, I may add that the conclusions which follow are only applicable to plants under precisely the same conditions as those under which my experiments were conducted.

(1) I note, first, that experiments Nos. 3 and 4 confirm in the most precise manner the general fact of the accelerating influence exercised by light upon the absorption of oxygen; but, these experiments having been carried out at a higher mean temperature, the differences in the quantity of oxygen absorbed in the light and in the dark are generally less than in the first series of experiments.

(2) As to the exact relative quantities of carbonic acid exhaled, it was a little more for the castor-oil plant in the dark than in the light, the contrary being the case for the scarlet runner bean. From this we might conclude that the influence of light produces doubly favorable effects upon the germination of the castor-oil plant, (*a*) by increasing the absorption of oxygen and (*b*) by diminishing the exhalation of carbonic acid, thereby increasing the gain of oxygen by reducing the expenditure of carbon and oxygen. (It must not be forgotten, in this explanation, that one volume of carbonic acid gas contains one volume of oxygen.) From this particular point of view the scarlet runner bean seems to be less favored than the castor-oil plant, although the excess of the quantity of carbonic acid exhaled by either placed in the light is nearly insignificant when compared with that exhaled by the same species kept in the dark.

(3) In the dark the ratio $\frac{CO_2}{O}$, as determined by four experiments divided equally between the seed of the castor-oil plant and those of the haricot bean, was at least a third more in favor of the latter than the ratio obtained for the castor-oil plant. The length of the experiment appears to me to have exercised a certain influence upon this ratio. Thus, for the castor-oil plant the figures reached 0.586 in experiment No. 2, which lasted about four days, and 0.771 in experiment No. 3, which lasted five days. The same was the case with the haricot bean; the result was 1.138 for experiment No. 4, which terminated during the fourth day, and 1.034 for experiment No. 5, which was prolonged until the sixth day. In a word, the prolongation of the experiment tends to render the ratio $\frac{CO_2}{O}$ equal to unity. With the duration of the experiment this ratio rises in those cases where it is below 1, but diminishes where it is above 1, until the seed is consumed and the period of vegetation, properly so called, arrives, during which latter time the final limit may be reached when the quantities of oxygen absorbed and the carbonic acid exhaled balance perfectly.

(4) In the light the ratio $\frac{CO_2}{O}$ is about a third more for the

haricot bean than for the castor-oil plant. But the sum obtained in experiment No. 2 was very much below that stated in experiment No. 5. The duration of this experiment and its prolongation until the approach of the vegetating period appears to me to account for this difference. This hypothesis is supported by the results of experiments Nos. 1 and 4, the first having lasted six days and the other less than four.

(5) By comparing the ratio $\frac{CO_2}{O}$ for similar experiments made in the light and in the dark, we see that there is always a difference of a quarter of the value of this ratio in favor of the dark; or, in other words, a seed placed in the dark always exhales more carbonic acid for the same quantity of oxygen absorbed than a seed kept in the light, even although sometimes, as we showed in experiment No. 3, the absolute quantity of carbonic acid exhaled is less in the light than it is in the dark. Finally, while in the light the carbonic acid released is always much less in quantity than the oxygen absorbed, the contrary may be the case in the dark, where the absolute amount of carbonic acid may even exceed the absolute quantity of oxygen, as is proved in experiment No. 4, where the absorption of oxygen 37.36 corresponds to an exhalation of 42.54 of carbonic acid.

(6) In order to consider the influence exerted upon the ratio $\frac{CO_2}{O}$ by the nature of the grain itself under different conditions as to light and darkness, it is only necessary to consult the conclusions which precede, and note the marked differences that distinguish the albuminous and oily seed of the castor oil from the nonalbuminous and starchy haricot bean.

(7) The facts which precede complete the explanation already given of the transformation of legumin into asparagin under the influence of light. In general, the absorption of a greater quantity of oxygen only assures the formation of asparagin in so far as the amount of carbonic acid exhaled is less than the amount of oxygen absorbed; since asparagin is poorer in carbonic acid and richer in oxygen than legumin, all the conditions favorable to that formation are to be found demonstrated in the results of experiment No. 4, with seeds exposed to the light. It is very probable that a portion of the oxygen which had disappeared and that was not found as carbonic acid was absorbed by the albuminoids when forming asparagin, and we know from other sources that this substance seems to form in the majority of seeds during the process of germination.

This absorption of oxygen during the period of germination is still greater in the castor-oil seed than in that of the bean. The oily seed, therefore, seems to be more favored by nature from a physiological point of view.

(8) We might be tempted to compare the ratio $\frac{CO_2}{O}$, obtained during the time of germination, with the same ratio during the period of vegetation. But the sum for the vegetating epoch has only been precisely fixed in the dark, which for green plants is entirely an abnormal state. As, on the other hand, it is impossible to gauge exactly

the quantity of oxygen absorbed and the amount of carbonic acid exhaled by a plant placed in the light and under natural conditions, it will easily be understood why we refrain from making any comparison until we are in possession of all the data necessary to carry out the calculation.

(9) The facts which precede convince me that the seeds of uncultivated plants germinating in the light are, all other conditions being equal, better distributed than the seeds of cultivated plants; that they possess a greater germinating power, an advantage which increases their chances for ulterior development.

Chapter III.

THE TEMPERATURE OF THE SOIL.

OBSERVATIONS AT HOUGHTON FARM AND GENEVA, N. Y., BY D. P. PENHALLOW.

In reference to the value of soil temperatures, Penhallow states (Agr. Sci., Vol. I, p. 78):

A proper knowledge of the temperature of the soil must serve to guide us in reference to the time of planting particular seeds and the depth at which they should be planted, as determined by the condition and character of the soil. When the farmer gently packs the earth over the planted seed he derives a measure of benefit in the higher temperature of the soil at that place, whereby germination is accelerated. Similarly, we can understand that cultivation during periods of excessive heat must tend to avert some of the evil results otherwise following from an excess of temperature. Moreover, in seasons of great or even of ordinary dryness a judicious system of irrigation must be of the greatest advantage, not only as supplying needed fluids for the general functions of growth, but as reducing the otherwise high temperature of the soil to a degree that is well within the danger limit and consistent with normal growth.

Penhallow also shows from observations at Houghton Farm and at Geneva, N. Y., that all layers of the soil within 3 inches of the surface have temperatures that depend not merely upon absorption of solar heat but also upon the cooling due to radiation and evaporation. The depression due to evaporation amounts to about 8° C. on the average of the warmer half of the year and is even more than this when hot days and strong dry winds produce an excessive evaporation.

OBSERVATIONS BY E. S. GOFF.

E. S. Goff adduces observations to show that the temperature of the water at the time when it enters into the roots from the soil has some relation to the temperature of the stem of the plant for a short distance above the surface soil, and that the distance up the stem to which this temperature is felt depends upon the rapidity of the flow of the sap, and therefore ultimately on the rapidity of transpiration from the leaves. (Agr. Sci., Vol. I, p. 134.)

OBSERVATIONS OF TEMPERATURE OF MANURED SOILS IN JAPAN BY GEORGESON.

Soil temperature must to some extent be affected by the heat given out by decaying manure and vegetation. On this subject Mr. C. C. Georgeson describes some experiments being made at Tokyo, Japan (Agr. Sci., Vol. I, p. 251), from which it appears that the temperature immediately after applying the manure was from 2° to 5° F. higher than in the unmanured soil, and this excess steadily diminished, but was still appreciable at the end of two months. The 2° of excess occurred when the manure was applied at the rate of 10 tons per acre, and the 5° of excess when applied at a rate of 80 tons per acre.

INFLUENCE OF RAIN ON TEMPERATURE OF THE SOIL AT MUNICH. (K. SINGER.)

The study of the earth temperatures at considerable depths is a problem for terrestrial physics, but for agricultural purposes we need only consider the temperature of the soil within 4 or at most 8 feet. The work of Karl Singer (1890) is sufficiently instructive to justify the presentation of his general results for use in studying the phænological phenomena of Europe. In a simple diagram Singer summarizes at a glance the mean temperature of the soil at any depth between 1 and 7 meters for any day of the year, as it results from an average of thirty years of observations at the observatory at Bogenhausen, near Munich, Bavaria. The series of observations includes, in fact, four sets of earth thermometers, two of which were on the northwest side of the observatory and the other two on the southeast side; the diagram and the following summary of results relate to the average of the pair on the southeast side. Each set of thermometers consisted of five, whose bulbs were buried at depths of 4, 8, 12, 16, and 20 Bavarian feet, respectively, or 1.2, 2.4, 3.6, 4.8, and 5.9 meters, respectively. The lines given in this diagram are thermal isopleths, viz, curves of equal temperature for successive depths and days, the days being represented by vertical lines and the depths by the horizontal lines. The following paragraphs express the general results of Singer's work as far as it bears upon the growth of plants:

(1) The normal mean temperature of the earth for twenty-five years (1861–1885) at Bogenhausen, near Munich, at certain depths, is as follows:

Thermometer.	Depth.		Mean temperature.	Amplitude.
	Bavarian feet.	Meters.		
			° C.	° C.
No. I	4.2	1.3	9.18	11.64
No. II	8.2	2.5	9.16	7.64
No. III	12.2	3.6	9.12	5.24
No. IV	16.2	4.8	9.12	3.48
No. V	20.2	6.0	9.06	2.12

(2) The mean temperature of the earth at a depth of about 1 meter below the surface exceeds the mean temperature of the air [at a meter above the surface] by more than 2°. The important influence of the considerable altitude above sea level of the place of observation is to be recognized in this result.

(3) The decrease of the annual amplitude with increasing depth for the adopted interval of 4 Bavarian feet, or 1.17 meters, amounts to 12.18° C., or very nearly one-third of the original amplitude of the atmospheric temperature. The amplitude $\triangle P$ in centigrade degrees at the depth P in meters is represented by $\log \triangle P=1.2620-0.1508\ P$. Whence we compute the amplitudes given in the last column of the preceding table.

(4) The epoch of the occurrence of the extreme and mean temperatures for the highest thermometer, No. I, are: Minimum, 2d of March; first mean, 21st May; maximum, 24th August; second mean, 15th November. These are therefore separated from each other by intervals of about $2\frac{2}{3}$, 3, $2\frac{2}{3}$, $3\frac{1}{2}$ months, respectively. For each step downward of 4 feet, or 1.2 meters, in depth, the occurrence of the epoch of extreme temperature is retarded on an average 21 days and that of the mean temperature 24 days; therefore an almost uniform distribution of these dates is brought about down to a depth of 20.2 feet, or 6 meters, where the minimum occurs on the 23d of May, the first mean on the 24th August; the maximum 17th November, and the second mean on the 24th February.

(5) The actual temperatures of the ground from 1861 to 1889, at the upper stage of 4.2 feet, or 1.3 meters, or thermometer No. I, did not fall below 2° C. or rise above 17° C. At the lower levels they ranged between 4° and 14°, 5° and 13°, 6° and 12°, 7° and 11°, respectively.

(6) By a careful consideration of the state of the weather it is possible in every case to account for the connection between the fluctuations of the temperature of the air and that of the earth.

The following generalizations refer to the climate of the South Bavarian Plateau only and to the four seasons of the year:

(7) In mild and, as usual, rainy, winter months, there is no material rise in the temperature of the earth relative to the average temperature curves, particularly at great depths, but generally a lowering of temperature.

(8) Mild, and at the same time dry, winters are associated with a tendency of the earth temperature to rise above the average.

(9) The earth temperatures exhibit a tendency to fall, if not already too low, during winters in which, with alternate freezing and thawing, the mean temperature is below the normal.

(10) In the same way even a covering of snow can only to a limited extent prevent the cooling of the earth when severe cold follows the mild and rainy weather of the first part of winter.

(11) In continuous severe winters, on the contrary, when even December generally brings a permanent covering of snow, the negative departure of the earth temperature is either limited to the higher strata or is unimportant.

(12) A warm spring, which, as a rule, brings only a moderate quantity of rain, causes a relatively decided rise of the earth temperature.

(13) When a cold and rainy late winter is directly succeeded by warm spring months, the temperatures of only the upper strata of the ground rise, while those of the lower strata may fall still further below their normal values.

(14) In certain warm and at the same time rainy springs the earth temperatures remain on an average unchanged with respect to the normal [or the cold rain counterbalances the warm weather. C. A.]

(15) An exceptionally cold spring, which is generally distinguished by heavy snows, is, with few exceptions, accompanied, and to a considerable depth, by a notable lowering of the temperature of the ground in comparison with its normal temperature.

(16) In cold and at the same time dry spring weather the relative lowering of the temperature of the ground will generally be inconsiderable if it has not been preceded by an immediate very rainy season.

(17) A warm summer is always accompanied by a high temperature of the ground or by a rise of its temperature. The increase is the more decided the more the excess in the temperature of the air is accompanied by a large quantity of rain or has been immediately preceded by it. In warm and comparatively dry summers the rise of the earth's temperature does not perceptibly exceed the normal.

(18) The relative lowness of the temperature of the soil which follows without exception a cool summer generally extends down only to a comparatively moderate depth, scarcely to 4 meters. Those months in which we find it extending to 6 meters will be found to have been at the same time rainy months.

(19) A warm autumn, with very few exceptions, causes a corresponding small rise in the temperature of the soil, but this may even, on the contrary, become a fall when the late autumn, by reason of much rain, resembles a mild type of winter.

(20) Low air temperature is generally accompanied in autumn by an excess of rain, the consequence of which, as regularly and frequently observed, is a falling in the temperature of the earth.

(21) In the rarer cases of cool and dry autumns there is observed only a very inconsiderable influence on the temperature of the earth.

(22) The dampness of the soil is (under the climatic influences prevailing in Munich) sufficient to allow the variations in the temperature of the air in winter and spring to exercise a decided influence upon those of the soil, whereas in summer an excess of rain would be

necessary to accomplish this, and that, too, to a greater degree if the soil be covered with vegetation. The phenomena of autumn generally resemble closely those of summer.

(23) In general the fluctuations in the temperature of the earth are not less dependent on the precipitation than on the variations in the temperature of the air.

SOIL TEMPERATURES AS AFFECTED BY SURFACE SLOPE AND COVERING (WOLLNY).

In reference to the effect of the slope of the earth's surface on the temperature of the soil, Wollny (1888, p. 364) has made an extensive series of measurements at Munich from which he draws the following conclusions in continuation of those published by him in 1883. His temperatures were measured bihourly at a depth of 15 centimeters under both fallow soil and grass sod; the differences referred to amounted to 3° and 4° F. in individual cases, but on the average to scarcely 1° F.

(1) That soil whose exposure is toward the south is the warmest, then comes the east, then the west, and finally the north exposure.

(2) The southern exposure is warmer in proportion as the inclination to the horizon is greater.

(3) The difference of temperature between the north and south exposure is much greater than between east and west.

(4) The difference in the warming of the soil for north and south exposures is greater in proportion as the surfaces have a greater inclination.

Wollny (1888, p. 415) has also investigated the influence of the covering of straw and chaff on the temperature and moisture of the soil. He finds the following conclusions:

(1) That at a depth of 10 centimeters the naked soil is warmed more with rising air temperatures and is cooled more with falling air temperatures than under any one of the different forms of straw covering.

(2) That the variations in the temperature within the straw litter are very much less than in the earth.

(3) That the earth is in general somewhat colder than the material of which the litter is made, except when the latter is moss.

(4) That among the various materials forming a litter the pine needles are warmed the most, the oak leaves and the fir-tree needles are less warm, while the litter of moss is the coldest.

The different temperatures observed were as follows, on the average of the months April to September: Pine needles, 16.93° C.; oak leaves, 16.62° C.; fir needles, 16.34° C.; the naked soil at a depth of 10 centimeters, 16.18° C.; moss, 15.95° C.

The difference between the morning and evening temperatures shows:

(1) That the cooling during the night and the warming during the day is appreciably larger for the naked earth than for the various kinds of litter.

(2) That the pine needles warm up most during the day and the moss warms up least; that the fir needles cool most during the night and the pine needles least.

The power of retaining moisture varies with the different kinds of litter as follows:

(1) Any litter of forest leaves or needles is moister than the earth, but the moss is less moist than the earth; the gradation is from oak leaves, the highest, through fir needles to moss, the lowest.

With regard to evaporation Wollny shows that the naked earth loses a greater quantity of moisture by evaporation than do the various kinds of litter.

(2) That the moss litter evaporates the most, but the litter of forest leaves the least.

(3) That the quantity of evaporation is greater the thinner the layer of the litter.

In general, then, the litters of leaves and of pine needles give up the rain water that falls upon them to the ground beneath in larger proportion, but still continue to be very moist because they lose, relatively, little water by evaporation; furthermore, that the moss litter is distinguished by large variations in its contained water because it has on the one hand a large capacity for water and on the other hand a very considerable evaporating power.

SOIL TEMPERATURES OBSERVED AT GREENWICH, ENGLAND.

Among the limited number of long-continued series of observations of temperatures of soil near the surface is that maintained at Greenwich Observatory, England, since June, 1846. This series embraces observations at considerable depths that will not interest the student of agriculture, but we reproduce in the following table the results of observations at 1 inch in depth, as given in the annual volumes of the Greenwich Observatory for 1878, and as given in J. D. Everett's memoir of 1860. These soil temperatures can be used in any subsequent study of English crops throughout the southern half of England or in analogous climates.

Monthly and annual means of noonday readings of a Fahrenheit thermometer whose bulb is 1 inch below the surface of the soil at Greenwich Observatory.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual mean.
	°	°	°	°	°	°	°	°	°	°	°	°	°
1847	37.8	38.0	42.9	47.2	58.0	61.1	67.4	64.7	56.9	54.5	48.7	44.5	51.81
1848	37.4	44.1	44.6	49.5	61.6	61.7	65.0	60.8	58.8	53.5	45.5	45.5	52.33
1849	41.5	43.6	44.3	46.3	56.5	63.3	65.0	65.2	61.8	53.0	46.5	41.1	52.34
1850	36.7	44.4	41.9	50.4	53.0	64.1	65.2	63.0	58.7	49.5	48.7	42.7	51.52
1851	44.2	42.7	44.0	48.5	54.8	62.2	63.8	65.5	60.0	54.7	41.2	42.2	51.98
1852	42.8	42.0	43.0	49.9	55.1	59.4	71.0	65.2	61.1	50.2	50.4	48.0	53.18
1853	44.3	37.0	41.8	47.4	55.7	62.3	63.2	64.1	60.3	55.1	44.9	38.0	51.18
1854	40.6	41.6	45.3	52.7	54.2	59.8	64.4	64.6	61.6	52.9	44.1	42.9	52.06
1855	38.4	33.4	41.0	48.9	52.9	61.3	65.6	66.0	60.9	54.7	44.3	38.3	50.47
1856	41.5	43.3	41.7	50.4	52.6	63.0	64.8	66.7	59.0	54.5	43.9	41.9	51.94
1857	38.9	40.7	43.7	48.3	57.6	65.6	67.0	67.9	62.5	55.2	48.8	46.6	53.57
1858	39.6	37.8	42.2	49.6	54.3	68.6	64.5	66.0	62.7	54.2	42.2	42.4	52.01
1859	42.4	43.5	47.3	49.3	55.8	64.4	70.7	66.7	59.7	54.4	44.3	39.3	53.15
1860	40.9	37.4	42.1	45.2	56.7	58.2	61.3	60.4	57.0	52.4	44.0	39.9	49.62
1861	35.5	42.6	44.6	47.7	54.9	63.2	64.6	66.2	60.3	57.5	43.9	42.6	51.97
1862	40.7	42.9	45.6	50.6	57.8	60.0	62.6	63.5	60.6	54.3	42.7	44.0	52.11
1863	43.2	43.2	45.0	51.1	54.3	60.5	64.0	63.9	57.6	54.3	48.0	45.6	52.56
1864	39.6	39.0	43.2	50.0	56.3	60.0	63.2	62.2	59.5	54.0	45.4	41.6	51.17
1865	38.8	38.9	39.3	53.3	57.8	64.4	66.1	62.5	65.6	54.7	47.5	45.1	51.83
1866	44.1	43.1	42.0	50.3	52.8	63.3	65.0	61.7	59.0	55.2	47.2	44.9	52.38
1867	38.3	46.1	40.7	49.9	55.9	61.4	62.6	64.1	60.5	52.6	45.2	39.9	51.43
1868	39.4	44.5	45.9	50.5	59.8	64.3	69.9	66.7	63.0	52.2	45.0	47.0	54.02
1869	43.0	46.8	40.8	51.5	54.3	58.6	66.2	63.2	60.9	52.4	45.8	40.5	52.00
1870	40.1	38.1	42.5	50.0	56.1	64.2	67.1	63.8	58.6	52.9	44.3	38.1	51.32
1871	36.2	42.0	45.0	49.6	54.2	58.4	63.7	66.6	60.7	52.0	41.2	39.2	50.73
1872	41.6	44.6	45.0	49.8	53.4	61.5	66.9	63.9	60.6	50.8	47.1	43.0	52.36
1873	42.8	36.4	42.4	48.5	53.3	61.2	66.0	65.2	57.7	51.4	45.7	42.7	51.11
Average	40.38	41.40	43.25	49.50	55.54	62.08	65.44	64.46	60.21	53.45	45.43	42.50	51.97

SOIL TEMPERATURES OBSERVED AT BROOKINGS, S. DAK.

Among the agricultural experiment stations in the United States whose work will be used in this preliminary report are some whose observations of the temperature of the soil will be needed for comparison with the observations on the growth of plants and resulting crops or for demonstrations of the relations between the temperature of the air and of the soil. The following table gives for Brookings, S. Dak., the daily maximum readings of the thermometer in the air and shade, the daily rainfall, the maximum temperatures of the soil at depths of 2 inches and 12 inches as far as published in Experiment Station Bulletin No. 6 for a portion of the summer of 1888. These figures show that in summer and for the growing season generally the temperature of the soil near the surface is higher than that of the air in the shade only when the sun shines on it, and that it is lower than the temperature of the air in the shade only when the radiation cools it at nighttime or when the rain falls in the daytime and is for a short time followed by rapid evaporation. The average

of the maximum temperatures of the air, less the temperatures of the soil at 2 p. m. at a depth of 2 inches was 2.3° F. in July, 1888, and 3° F. in August, 1888. On the other hand, the average value of the maximum temperature of the air, less the temperature of the soil at 2 p. m. at a depth of 12 inches was 12° F. for the observations here given, scattered through July and August, 1888.

Temperatures at Brookings, S. Dak.

[Lat. 44° 20′ N.; long. 96° 40′ W.; altitude, 1,000 feet.]

Date, 1888.	Maximum air temperature.	Daily rainfall.	Soil temperatures (readings at 2 p. m.).		Date, 1888.	Maximum air temperature.	Daily rainfall.	Soil temperatures (readings at 2 p. m.).	
			Depth 2 inches.	Depth 12 inches.				Depth 2 inches.	Depth 12 inches.
	° F.	Inch.	° F.	° F.		° F.	Inch.	° F.	° F.
July 13	69.0	0.09	69	....	Aug. 9	63.0	0.0	63	60
14	81.5	.11	81	....	10	60.0	.40	....	....
15	81.0	.0	77	....	11	62.0	.01	....	....
16	82.0	.0	81	....	12	74.0	.0	....	....
17	79.0	.0	71	....	13	79.0	.0	....	....
19	86.0	.0	82	....	14	75.0	.50	67	....
23	82.0	.0	84	....	15	69.0	.20	63	....
24	83.0	.0	86	....	16	72.0	.0	71	....
25	82.5	.0	84	....	17	73.0	.0	72	....
26	89.0	.0	83	....	18	82.0	.0	71	....
27	88.0	.0	81	....	19	72.0	.42	....	....
28	94.0	.0	85	67	20	80.0	.01	....	....
29	89.0	.0	70	70	21	79.0	.0	70	....
30	101.0	.23	103	76	22	82.0	.0	78	78
31	73.0	.0	87	65	23	83.0	.0	76	71
Aug. 1	77.0	.0	75	67	24	89.0	.0	77	70
2	91.0	.0	85	68	25	94.0	.0	82	75
3	83.0	.0	93	70	26	84.0	.0	....	....
4	89.0	.0	85	71	27	89.0	.0	84	78
5	79.0	1.27	....	....	28	82.0	.0	....	....
6	76.0	.12	83	68	29	94.0	.0	....	....
7	71.0	.0	77	67	30	78.0	.0	86	71
8	76.0	.28	63	64	31	69.0	.0	83	68

It would appear that the reading of the soil temperature is frequently omitted when rain falls; this is a bad practice, but the records suffice to show us that in this dry country and during the summer time the maximum surface temperatures of the soil will not differ much from the maximum temperatures of the air, while the soil temperatures at 12 inches will closely follow the mean temperature of the air. The latter mean, viz, one-half the sum of the maximum and minimum record for any day is greater than the mean temperature of the layers of soil at 2 and 12 inches depth, as observed at 2 p. m., by about 6° F.

SOIL TEMPERATURES OBSERVED AT AUBURN, ALA.

As an illustration of soil temperatures in a southern locality I have chosen the following record for 1889 at Auburn, Ala., where the agricultural experiment station has maintained three sets of buried thermometers, two of them in sandy soils on hills and one in moist bottom land near the banks of a small stream. It appears from these records that the difference in temperature in the growing season between the so-called "cold wet" and "warm dry" soils averages but a few degrees; in fact, I doubt whether it is appreciable from observations having the accuracy of those here given. Thus at 3 inches depth and during the warm half of the year the maximum temperatures on the hill average 1° F. above those in the bottom land, while the minimum temperatures on the hill average 2° F. colder than those of the bottom lands. The temperatures here given are the averages of the maxima and minima and are taken from successive monthly reports and from Bulletin No. 18 of the Alabama Agricultural Experiment Station. In these, as at most other United States stations, the correction for the temperature of the long stem of the thermometer still remains to be applied. A comparison of the temperature at 3 inches depth with the maximum and minimum air temperature shows that the soil is warmer than the air in the daytime from April to October, inclusive, and warmer than the air at the minimum temperatures throughout the year. This latter is true for the minimum temperatures of the soil down to a depth of 96 inches, but the excess of maxima temperatures of the soil over those of the air during the daytime in summer ceases a little below 6 inches. Evidently the temperature of the soil is sufficiently high to allow of the growth of some form of vegetation throughout the year.

Extremes and means of soil temperatures for 1889, as observed at Auburn, Ala.

[Lat. 32°.6 N.; long. 85°.4 W.; altitude, 732 feet.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Air temperatures.	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
Mean air temperature	46.9	46.3	54.7	62.5	70.1	76.1	80.7	77.6	74.8	62.3	58.1	57.8
Mean radiation temperature	39.7	36.8	43.2	55.6	57.2	65.8	70.0	67.5	65.2	49.5	42.9	45.5
Maximum air temperature	67.0	75.0	76.0	82.0	89.0	91.5	98.0	92.5	93.0	82.0	76.0	74.0
Minimum air temperature	23.0	16.5	30.0	38.0	45.0	46.0	67.5	63.0	48.0	38.0	24.0	29.0
Maximum terrestrial radiation temperature	51.0	66.5	54.0	62.0	63.0	74.0	73.5	72.5	78.0	60.0	60.0	59.5
Minimum terrestrial radiation temperature	21.0	24.0	32.0	37.0	43.0	43.0	60.0	62.0	48.0	36.0	22.0	30.5

Extremes and means of soil temperatures for 1889, etc.—Continued.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Soil temperature.												
SANDY SOIL ON A HILL; OFTEN CULTIVATED DURING CROPS.												
3-inch depth:	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*
Maximum	63.5	69.0	73.5	82.5	92.5	96.0	101.5	95.0	96.5	84.5	69.5	69.0
Minimum	33.5	32.0	37.0	48.5	52.0	52.0	71.5	69.5	54.5	45.0	35.0	35.0
6-inch depth:												
Maximum	61.0	76.5	68.5	79.5	89.0	92.0	98.0	92.5	92.5	82.5	68.5	65.0
Minimum	35.5	34.5	39.0	50.0	55.0	55.0	73.5	70.5	57.5	48.0	37.0	37.5
24-inch depth:												
Maximum	52.5	57.0	58.5	67.0	76.5	80.0	86.0	82.0	89.5	74.0	65.5	60.0
Minimum	46.5	44.0	49.0	58.0	64.5	68.5	77.0	78.0	72.0	62.5	52.0	50.0
48-inch depth:												
Maximum	53.5	53.0	56.5	63.0	71.5	75.0	79.5	79.0	84.5	74.5	69.0	60.5
Minimum	51.5	48.0	50.5	56.5	63.0	69.5	74.5	77.0	75.0	67.0	58.0	56.5
96-inch depth:												
Maximum	59.5	56.5	56.0	60.5	62.5	69.0	73.0	73.5	76.5	74.5	70.0	65.0
Minimum	56.5	54.5	54.5	54.0	60.0	65.5	69.0	73.0	73.5	70.5	64.0	62.0
BOTTOM LAND ON BANK OF SMALL STREAM.												
3-inch depth:												
Maximum	60.5	67.0	69.0	80.5	92.5	95.0	101.0	96.0	96.0	84.5	71.5	69.5
Minimum	35.5	35.0	41.5	47.5	55.0	55.0	74.0	70.5	56.5	45.0	34.0	34.0
6-inch depth:												
Maximum	58.5	65.0	66.5	79.5	88.0	91.0	97.5	93.0	92.0	82.0	69.0	65.0
Minimum	39.0	38.0	44.0	52.0	59.0	58.0	76.0	73.0	60.0	49.0	37.0	36.0
24-inch depth:												
Maximum	54.0	57.5	58.0	67.5	76.0	80.0	85.5	82.0	82.5	74.5	66.0	60.0
Minimum	48.5	46.0	51.0	58.5	65.0	69.5	77.0	78.5	72.5	63.0	52.5	50.0
48-inch depth:												
Maximum	54.5	54.0	57.0	64.0	71.0	75.0	79.5	79.0	79.0	75.0	68.0	61.0
Minimum	52.5	50.5	51.5	57.0	63.5	69.5	74.5	77.0	75.0	67.5	59.0	57.0

SOIL TEMPERATURES OBSERVED AT PENDLETON, OREG.

Among the United States experiment stations for which soil temperatures have been published, I quote the following observations made by Mr. P. Zahner, voluntary observer at Pendleton, Oreg., (lat. 45°.7 N.; long. 112°.2 W.; altitude, 1,122 feet), because it represents a climate so different from that found in the same latitude east of the Rocky Mountains. A number of observations of diurnal periodicity are given by Zahner, and a shorter series is at hand for Corvallis, Oreg. (lat. 44°.5 N.; altitude, 150 feet). The comparison between these shows that the Pendleton air and soil are appreciably warmer than the Corvallis in July, August, and September, but colder in November and probably also in December. In general the maximum soil temperature at Pendleton at all depths follows that of the

daily maximum air temperature. Rainfall lowers the temperature of the soil, as on March 18, 1890, at 8 inches depth by 2° F., but at 24 inches depth by 0.5° F. At 12 inches depth the soil was not frozen throughout the year, but at 8 inches it was frozen up to the 7th of March. The soil temperatures were read daily at 3 p. m.; the soil was naturally dry and light, and was covered with a thin grass. The thermometers were maximums and minimums, apparently read from above ground without being disturbed in their positions.

Observations at Pendleton, Oreg., in 1890.

[From the Monthly Reports of the Oregon State Weather Bureau.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
Air temperature.	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*
Absolute maximum temperature	60.0	58.0	70.0	89.0	91.0	100.0	105.0	99.0	90.0	73.0	68.0
Absolute minimum temperature	−16.0	−13.0	10.0	21.0	30.0	36.0	40.0	44.0	26.0	24.0	14.0
Mean of maximum temperature	29.1	39.7	51.5	67.9	75.0	76.6	87.2	88.5	80.6	64.5	57.2
Mean of minimum temperature	13.0	20.5	32.5	36.6	45.2	49.4	50.5	49.1	89.5	34.8	23.6
Monthly mean temperature	21.0	30.1	42.0	52.2	60.1	63.0	68.8	68.8	60.0	49.6	40.4
Precipitation.											
Total monthly rainfall	[a]1.19	[a]1.52	[a]2.04	[a]0.17	[a]1.51	[a]1.80	[a]0.08	[a]0.07	[a]0.27	[a]0.63	[a]0.01
Soil temperature.											
4-inch depth:											
Maximum	38.0	49.0	55.0	76.0	81.0	90.0	92.0	86.0	80.0	64.0	53.0
Minimum	16.0	26.0	30.0	48.0	60.0	61.0	74.0	75.0	62.0	53.0	40.0
Mean	26.7	37.3	44.9	62.2	72.3	74.2	84.6	83.3	73.2	57.4	45.8
8-inch depth:											
Maximum	33.0	44.0	49.0	68.0	72.0	80.0	83.0	78.0	71.0	60.0	49.0
Minimum	20.0	29.0	30.0	48.0	59.0	61.0	72.0	71.0	64.0	50.0	38.0
Mean	27.8	36.6	40.9	55.3	66.3	68.4	77.6	75.8	66.5	53.7	43.2
12-inch depth:											
Maximum	34.0	41.0	46.0	62.0	67.0	71.0	78.0	85.0	70.0	63.0	51.0
Minimum	27.0	33.0	33.0	46.0	58.0	60.0	69.0	71.0	64.0	51.0	40.0
Mean	30.4	37.1	39.8	52.2	63.1	65.8	73.7	73.3	65.7	54.7	45.2
24-inch depth:											
Maximum	38.0	40.0	45.0	58.0	64.0	66.0	74.0	73.0	70.0	64.0	54.0
Minimum	33.0	35.0	36.0	45.0	58.0	61.0	68.0	71.0	64.0	54.0	44.0
Mean	34.6	38.1	40.1	50.1	60.9	63.7	30.7	71.7	66.7	57.3	48.5

[a] Inches.

SOIL TEMPERATURES OBSERVED AT MONTREAL, CANADA.

As illustrating temperatures of the ground in a very cold locality, I quote the work of Messrs. C. H. McLeod and D. P. Penhallow, of McGill College Observatory, Montreal, who have maintained a series of observations of the temperature of the earth by Becquerel's method, in which the temperature of a coil of wire in the laboratory is brought to equality with the temperature of a similar coil buried in the

earth. The following table gives the mean temperature for the ten-day periods ending on the dates given in column 1 and at a depth of 1 foot below the surface of the ground. Temperatures are given by them for other depths, as also for the air; the total rain and snow is also given. An investigation of the connection between earth temperature and the development of vegetation is being carried on by them, but as no results have as yet been published I give merely their soil temperatures at a depth of 1 foot, which usually agree, within a degree centigrade, with the average temperature of the air for ten days.

Mean temperature of the soil at a depth of 1 foot for periods of ten days at Montreal, Canada.

End of period.	Average soil temperatures.	End of period.	Average soil temperatures.	End of period.	Average soil temperatures.
1888.	° C.	1889—Continued.	° C.	1890—Continued.	° C.
November 11	6.3	July 9	21.1	March 6	1.0
November 21	2.3	July 19	20.4	March 16	0.7
December 1	0.4	July 29	21.5	March 26	0.4
December 11	0.9	August 8	21.2	April 5	0.5
December 21	0.8	August 18	18.7	April 15	0.6
December 31	0.4	August 28	18.9	April 25	5.3
1889.		September 7	19.6	May 5	7.4
January 10	0.5	September 17	18.4	May 15	9.1
January 20	0.6	September 27	13.6	May 25	11.7
January 30	0.2	October 7	11.0	June 4	15.0
February 9	0.2	October 17	7.1	June 14	15.5
February 19	−0.4	October 27	5.0	June 24	17.6
March 1	−0.1	November 6	4.7	July 4	21.1
March 11	−0.3	November 16	4.3	July 14	20.7
March 21	−0.2	November 26	3.0	July 24	20.7
March 31	−0.5	December 6	1.2	August 3	21.7
April 10	−0.5	December 16	1.0	August 13	21.9
April 20	3.7	December 26	0.9	August 23	18.7
April 30	6.4	1890.		September 2	16.5
May 10	12.7	January 5	1.3	September 12	17.2
May 20	15.3	January 15	1.9	September 22	14.9
May 30	14.7	January 25	1.4	October 2	11.1
June 9	15.5	February 4	1.1	October 12	10.1
June 19	18.8	February 14	0.8	October 22	8.8
June 29	19.2	February 24	0.8	November 1	6.8

This series seems to show the powerful influence of a snow covering to keep the ground from cooling to very low temperatures during the winter. The minimum temperatures at 1 foot depth were —0.5° F. during the twenty days March 22 to April 10, 1889, and +0.4° F. during the ten days March 17 to 26, 1890.

METHODS OF MEASURING SOIL TEMPERATURE.

As it is very important that there should be numerous observations of soil temperature available for agricultural study, and as many persons are deterred by the expensiveness of the deep-earth thermometers, I would call attention to the fact that agriculture does not need to consider temperatures at depths below 4 feet.

Several methods of measuring deep-earth temperatures have been most thoroughly studied in the memoirs of Wild and Leyst of St. Petersburg, a summary of which I have prepared and will submit at another time. For accuracy and convenience nothing can exceed the thermophone devised by Henry E. Warren and George C. Whipple, of the Massachusetts Institute of Technology.

The soil thermometers constructed in accordance with suggestions made by Milton Whitney, of the South Carolina Experiment Station have been used by him at several stations and he has published a description of this new self-registering soil thermometer as follows (see Agr. Sci., Vol. I, p. 253; Vol. III, p. 261):

This is a modification of Six's form of thermometer in which the maximum and minimum temperatures are registered in one and the same instrument. The essential features of the thermometers are as follows: A cylindrical bulb 6 inches long, filled with alcohol. The bulb is protected by a somewhat larger cylindrical metal tube, containing numerous holes, and is to be placed 3 inches below the surface of the soil—i. e., so that the bulb will extend vertically between the depths 3 and 9 inches, respectively, in the soil. The tube carrying the alcohol extends some 6 or 8 inches above the surface of the ground, when it bends twice at right angles and descends again to the surface, bends at right angles twice, crossing the main stem, and is carried up about 6 or 8 inches again, where it terminates in a bulb partially filled with alcohol. The lower bend in this stem carries a column of mercury which is drawn back toward the bulb when the alcohol contracts, and pushes a steel index up to the minimum temperature on a scale which reads downward. This index is held supported in the alcohol by a little spring when the alcohol expands and the mercury leaves it, while another index is pushed up to the maximum temperature by the other end of the column of mercury. The indices are set by the help of a magnet.

The advantages claimed for this instrument are that it gives at once, without any calculation, the mean temperature of a definite depth of soil, for which we now use at least three thermometers, while it gives in addition the maximum and minimum temperatures, and need only be read once a day instead of three times, as at present. * * *

Thermometers can be made, of course, with bulbs longer or shorter than the one described. We adopted the length of 6 inches placed 3 inches below the surface, as in our experience that represents a layer of soil in which most of the roots of the cotton plants are contained. We expect to distribute a number of these instruments through the

State [South Carolina] and have records kept for us near signal-service stations in our typical soils—a method which could hardly have been arranged with the old form. * * * The great trouble about the instrument is the danger in transportation of having the index get down in the mercury column. For this reason it has to be transported in a box on gimbals to swing freely within a larger box, so that it will always remain upright. We had such a box made, capable of carrying eight or ten instruments.

From experiments at Houghton Farm (Agr. Sci., Vol. II, p. 50) F. E. Emory finds that the thermoelectric couple and galvanometer, as used by Becquerel, consumed much time and was frequently useless owing to atmospheric electricity and ground currents. Short-stem graduated thermometers, with bulbs immersed in oil and fastened at the lower end of a light wooden rod, gave good results when the temperature at the thermometer was not warmer than that of the overlying soil or the atmosphere; otherwise a circulation of air takes place. He finds that the telethermometer, giving a continuous record, answers his needs, but we know nothing of its accuracy.

T. C. Mendenhall (1885) describes a modified form of thermometer for observing the temperature of the soil at any depth, which he calls the "differential resistance thermometer." Experiments with this instrument at Washington, D. C., have shown him that it is much less troublesome than Becquerel's electric method, but still too troublesome to be recommended to any but persons accustomed to electric measurements. Mendenhall's arrangement consists essentially in utilizing the varying resistance of a platinum wire which extends from the upper end of an ordinary mercurial thermometer down into its bulb. The total resistance diminishes as the temperature rises and allows the current to flow through less platinum but more mercury. The changes in the resistance are measured by the galvanometer, but he hopes to substitute for this the telephone, which will make the apparatus more convenient for general use.

[It is desirable that Mendenhall's method, or Becquerel's, or the thermophone be provided in connection with the ordinary buried long-stem thermometers in order that by an annual or more frequent set of comparative observations the changes in the zero point of ordinary thermometers may be detected.—C. A.]

Chapter IV.

THE INFLUENCE OF SUNSHINE ON ASSIMILATION AND TRANSPIRATION.

CHEMISTRY OF ASSIMILATION (ABBOTT).

The atmosphere is composed of about 79 per cent of nitrogen and 21 per cent of oxygen when we consider their volumes, but 77 per cent of nitrogen and 23 per cent of oxygen when we consider their relative weights. With these gases there are mixed small quantities of carbonic-acid gas, ammonia, hydrocarbons, and other impurities. With this " dry atmosphere " there is intermixed a very variable quantity of aqueous vapor or moisture, which in extreme cases may amount to as much as 5 per cent, by weight, of the dry air. These are the elements that are to be compounded by sunshine and heat in the laboratory of vegetation.

By respiration the leaves of plants, when in the dark, absorb oxygen from the air and set free carbonic-acid gas.

By assimilation, as shown by Garreau, these same leaves in the sunshine absorb carbonic-acid gas from the air and set free oxygen, retaining the carbon in new compounds. Assimilation is a process of greater intensity than respiration. Respiration is a process analogous in its results to that occurring within every animal organism, but assimilation is a process peculiar to the plant life.

By transpiration the leaves rid themselves of the superfluous water that, as sap, has served its purpose in the process of assimilation by bringing nourishment from the soil and delivering it up to the cells of the plant; a small portion of the nourishment and of the water may have been absorbed by the cells in the trunk of the tree, the stem of the vine, or the stalk of the grain and grass, but the majority of the water is removed by transpiration at the surface of the leaves in order to make room for fresh supplies of sap. Some water always remains in the cells of the seeds and grains until they are dried after maturity, but a well-dried crop contains relatively little water. This transpiration is stimulated by, and almost entirely depends upon, the action of sunshine on the leaves; it precedes evaporation.

Evaporation is not transpiration; the former takes place from the surface of water existing either in the moist earth or in films on leaf surface or in larger masses, while transpiration takes place through the cell wall and is a process of dialysis, an endosmosis and exosmosis

by which the cell takes in the sap, retains what it needs, and then gets rid of the water and the dissolved substances which it does not need. Thus the cell wall thickens and enlarges and the contents of the cell increase. The sap enters the cell from that side of the cell which is turned toward the interior of the plant or adjacent cells, and the rejected water penetrates the cell wall on that side of the cell which is exposed to the open air, and especially on that side exposed to the sunshine; having reached the outer surface of the cell wall on this side of the cell it is then evaporated. This endosmosis by which the sap enters the cell on one side, and the exosmosis by which it leaves the cell on the opposite side, constitute the fundamental mechanics of all vital activities; the chemistry of animal and vegetable life differs from the ordinary chemistry of the laboratory in that the former studies the behavior of the cell-wall toward the molecule, while the latter studies the behavior of the molecule toward the molecule. An interesting contribution to the development of this idea of the chemistry of the action of the cell is contained in two papers by Miss Abbott (now Mrs. Michael, of Philadelphia), published in 1887 in the Journal of the Franklin Institute; from the second paper I take the following extract:

> The botanical classifications based upon morphology are so frequently unsatisfactory that efforts in some directions have been made to introduce other methods.
>
> There has been comparatively little study of the chemical principles of plants from a purely botanical view. It promises to become a new field of research.
>
> The Leguminosæ are conspicuous as furnishing us with important dyes, e. g., indigo, logwood, catechin. The former is obtained principally from different species of the genus *Indigofera*, and logwood from the *Hæmatoxylon campechianum*, but catechin from the *Acacia catechu*.
>
> The discovery of hæmatoxylon in the *Saraca indica* illustrates very well how this plant, in its chemical as well as botanical character, is related to the *Hæmatoxylon campechianum*; also, I found a substance like catechin in the *Saraca*. This compound is found in the Acacias, to which class *Saraca* is related by its chemical position as well as botanically. Saponin is found in both of these plants, as well as in many other plants of the Leguminosæ. The Leguminosæ come under the middle plane of multiplicity of floral elements, and the presence of saponin in these plants was to be expected. * * *
>
> From many of the facts above stated, it may be inferred that the chemical compounds of plants do not occur at random. Each stage of growth and development has its own particular chemistry.

SUNSHINE AND TRANSPIRATION (DEHERAIN AND MARIÉ-DAVY).

Studies in the transpiration of plants were made in England as early as 1691 by S. H. Woodward, who experimented on aquatic plants. He showed that the consumption of water by the plant, or the weight of water evaporated from it, varied within narrow limits, while the growth of the plant under the same temperature and sunshine, varied according to the amount of nourishment in the water; thus of pure spring water 170 grains had to be evaporated in order to make an increase of 1 grain in the weight of the plant, but only 96 grains of the rich water of the Thames was required to make the same increase in the weight of the plant.

In 1848 Guettard, experimenting upon a creeping nightshade, showed that a plant kept in a warm place without sunshine would transpire less than one in a colder place with sunshine.

Deherain, as quoted by Marie Davy (1880, p. 231) introduced the leaves or stems of a living plant into a tube suitably closed; under these circumstances, by reason of the small, calm space of air surrounding the leaves, the evaporation in the ordinary sense would be inappreciable, but the transpired water was found to increase the weight of the tube, as shown in the accompanying table.

Sunshine and transpiration.

Plant.	Exposure.	Temperature.	Weight of water transpired per hour per gram weight of leaf.
		° C.	Gram.
Wheat	Sunshine	28	0.882
Do	Diffuse light	22	.177
Do	Darkness	22	.011
Barley	Sunshine	19	.742
Do	Diffuse light	16	.180
Do	Darkness	16	.023
Wheat	Sunshine	22	.718
Do	Darkness	16	.028
Do	Sunshine	28	.703
Do	Diffuse light	22	.060
Do	Darkness	22	.007

The effect of sunshine in stimulating transpiration is very clearly seen by a study of these figures. The small transpiration from the leaf when kept in darkness is supposed to be, at least in part, due to a persistency of the stimulus given to the plant by the light; so that, as is well known, the growth of the plant goes on at its maximum rate in the late afternoons, sometimes even after sunset, and does not attain its minimum until early morning.

Deherain also arranged the following experiments showing the effect of temperature. Some living leaves of wheat were kept within a glass tube which lay in a water bath at a uniform temperature of 15° C. and the following measurements taken:

In full sunshine the transpiration was 0.939 gram of water per hour per gram weight of leaf.

In darkness the transpiration was 0.016 gram of water per hour per gram weight of leaf.

The water bath was then reduced to a temperature of 0° C., and the temperature of the leaf within the tube must therefore have been at the freezing point. In this condition the transpiration in full sunshine was 1.088 grams of water per hour per gram weight of leaf.

Thus leaves in sunshine in free air at 28° C. and leaves in the air at 15° C., and again in the water bath at 0° C., give us the transpiration under these conditions 0.882, 0.939, 1.088, respectively. It is evident that this transpiration is not due to evaporation alone, else it would be independent of sunshine and depend wholly on heat; the decided differences here shown must be attributed to the special excitement of the cell by the solar radiation.

Marie Davy gives for July 24 and 25, 1877, the following record from a self-registering apparatus showing the diurnal periodicity of the transpiration from the leaves of four plants of haricot beans which were watered daily at 7 p. m.:

Diurnal periodicity of transpiration.

Hour.	Transpiration.	Hour.	Transpiration.	Hour.	Transpiration.
7 to 8 p. m.	4	4 to 5 a. m.	8	1 to 2 p. m.	120
8 to 9 p. m.	2	5 to 6 a. m.	32	2 to 3 p. m.	95
9 to 10 p. m.	2	6 to 7 a. m.	76	3 to 4 p. m.	67
10 to 11 p. m.	4	7 to 8 a. m.	99	4 to 5 p. m.	44
11 p. m. to 12 midnight.	4	8 to 9 a. m.	86	5 to 6 p. m.	25
12 midnight to 1 a. m.	4	9 to 10 a. m.	128	6 to 7 p. m.	10
1 to 2 a. m.	2	10 to 11 a. m.	153	7 to 8 p. m.	4
2 to 3 a. m.	4	11 a. m. to 12 noon	179		
3 to 4 a. m.	4	12 noon to 1 p. m.	143		

These same four plants showed the transpiration day by day, as given in the first column of the following table (Marie Davy, 1880, p. 239). The third and fourth columns, respectively, show the relation of this transpiration to the daily mean temperature and the daily mean radiation, as shown by the conjugate thermometers.

Insolation and transpiration for kidney beans at Montsouris.

Date, 1877.	Weight of transpired water.	Weight of transpired water divided by—		Date, 1877.	Weight of transpired water.	Weight of transpired water divided by—	
		Mean temperature.	Mean actinometric degrees.			Mean temperature.	Mean actinometric degrees.
	Grams.				*Grams.*		
July 16	0.686	4.1	1.16	July 24	0.706	3.8	2.00
17	0.422	2.6	1.36	25	1.300	7.1	2.17
18	0.727	4.4	1.21	26	0.991	5.3	1.92
19	0.543	2.9	1.23	27	1.255	6.7	2.46
20	0.577	3.3	1.56	28	1.426	7.8	2.64
21	1.127	9.1	1.24	29	1.277	5.9	2.97
22	1.606	6.2	1.81	30	2.167	7.6	3.55
23	1.204	5.4	1.88	31	2.710	8.4	3.15

The figures in the above table are influenced by the quantity of moisture in the soil; therefore Marie Davy occasionally omitted the evening watering, and the transpiration for the day after such omission was smaller. In general, Marie Davy concludes that the relation between transpiration and temperature is very variable from day to day, while that between transpiration and radiation is very regular, a regularity that would very probably be heightened if the cloudiness and the evaporating power of the wind, as depending on its dryness and velocity, had been considered. The belief is that sunshine excites the contraction of the stomata of the leaves and thus stimulates transpiration; but the stomata can not exude water to a greater extent than as supplied by the roots; therefore the transpiration is limited by the humidity of the soil adjacent to the roots. Thus on the 30th the radiation averaged 45.5 actinometric degrees, and the plant transpired 2.167 grams of water; on the 31st the radiation was 64.1 and the transpiration correspondingly increased to 2.710 grams; but on this day the reserve moisture in the soil was drawn upon very heavily, and in the evening the leaves of the plant were flabby and drooping and evidently wilting for the want of moisture.

The results by Deherain at temperatures of 15° C. and 0° C. and those by Marie Davy seem to demonstrate satisfactorily the slight influence of the temperature of the air as such upon transpiration.

Daubeny (1836), Deherain, and Wiesner have studied the effect of radiation in different parts of the spectrum, and their work shows that the radiations that are absorbed by chlorophyl, the so-called chlorophyl-absorption bands, are those that are efficient in stimulating transpiration; also that xanthophyl acts similarly, but weaker than chlorophyl; that the violet and ultraviolet have no appreciable influence; that the ultrared rays have an appreciable action, but feebler than the visible rays between the red and blue, notwithstand-

ing that their heating effect is usually greater than those of the visible spectrum.

The laws of growth or vitality are the laws of physics and mechanics and chemistry as applied to living cells. The changes that go on slowly in the plant are not the same as would go on rapidly in large masses of the same chemicals when treated as in the ordinary chemical laboratory. In the plant small masses are confined within the transparent walls of the cells until that subtile influence which we call radiation can do its work in bringing about new combinations of the atoms. It matters not whether we consider the radiation as an orthogonal vibration, as in light, or a promiscuous interpenetration of the molecules, as in heat, or a radial vibration, as in the waves of sound; whatever view we take of it, or whatever the details may be, even if it be a rythmic breaking up and re-formation of the molecules, the general characteristic of radiation is an extremely rapid motion along the molecules and atoms of matter. Therefore, by radiation we understand energy or momentum in the minute atoms that go to make up the molecules and the masses that we deal with; this implies that work is done by one atom upon its neighbor, which work, according to its style, we call light, heat, evaporation, etc. Assimilation and transpiration are among the forms of work in the growth of the plant that are due to the molecular energy contained in sunshine, and it is essential to progress in agriculture that there be kept a continuous register of the intensity and nature of the solar radiations that reach the plant. But this is a difficult problem, whose satisfactory solution has not yet been attained, although the work of Violle, Bunsen and Roscoe, Marie Davy, Marchand, Langley, Rowland, Hutchins, and many others have marked out the methods which seem most promising.

ANNUAL DISTRIBUTION OF SUNSHINE.

Humboldt (1845), in his chapter on "Climate," after comparing the climates and fruits of Europe, says:

These comparisons demonstrate how important is the diversity of the distribution of heat throughout the different seasons of the year for the same mean annual temperature, as far as concerns vegetation and the culture of the fields and orchards, and as well as regards our own well-being as a consequence of these conditions.

The lines which I call isochimenal and isotheral (lines of equal temperature for winter and summer) are not parallel to the isothermal lines (lines of equal annual temperature) in those countries where—notwithstanding the myrtle grows wild in its natural state, and where no snow falls during the winter—the temperature of summer and fall scarcely suffices to bring apples to full maturity. If to give a potable wine the vine shuns the islands and nearly all sea coasts, even those of the west, the cause is not only in the moderate heat of summer upon the seashore, a circumstance which is shown by thermometers exposed

in the open air and in the shade, but it consists still more in the difference between direct and diffused light, between a clear sky and one veiled with clouds, a difference which is still unappreciated, although its efficaciousness may be proved by other phenomena, as, for example, the union of a mixture of chlorine and hydrogen.

Humboldt adds:

I have endeavored for a long time to call the attention of scientists and physiologists to this difference; in other words, to the yet unmeasured heat which direct light develops locally in the cell of the living plant. (Cosmos, t. I, pp. 347–349.)

TOTAL QUANTITY OF HEAT REQUIRED TO RIPEN GRAIN.

Boussingault (1834), in his Rural Economy, computes the total quantity of heat required to ripen grain by multiplying the mean daily temperature of the air in the shade in centigrade degrees by the duration, in days, of the process of vegetation. This product is known as the number of "day degrees" that the plant has experienced or has required for the development from sowing to maturity. (See Annual Report Chief Signal Officer for 1881, p. 1208.) Boussingault's results are given in the accompanying table:

Day degrees required at different latitudes.

Plant and place.	Latitudes north.		Duration of the culture.	Mean air temperature during culture.	Product of the days by the temperature.
	°	′	*Days.*	° *C.*	*Day deg.*
Autumn wheat:					
Alsace	48	48	137	15.0	2 055
Alais	44	7	146	14.4	2 092
Kingston	41	50	122	17.2	2 098
Summer wheat:					
Alsace	48	48	131	15.8	2 069
Kingston	41	50	106	20.0	2 120
Cincinnati	39	6	137	15.7	2 151
Truxillo	9	00	100	22.8	2 208
Quinchuqui	0	14	181	14.0	2 230
Winter barley:					
Alsace	48	48	122	14.0	1 708
Alais	44	7	137	13.1	1 795
Kingston	41	50	92	19.0	1 738
Santa Fe	4	35	122	14.7	1 793
Cumbal	0	00	168	10.7	1 798

The above table shows that the total quantity of heat required increases as the latitude diminishes.

THE SUNSHINE AND HEAT REQUIRED TO RIPEN GRAIN.

Tisserand (1875) modifies Boussingault's hypothesis that growth varies with heat and time, but adopts the rule that the work done by a plant can be represented by the product of the mean temperature

by the number of hours of sunshine, only rejecting the useless night-time, just as one would reject the useless low temperature. In the absence of sunshine records he uses the number of hours between sunrise and sunset, or the duration of diffuse sunshine, and obtains for spring wheat and barley the data given in the accompanying table, where the last column may be said to give "sunshine hour degrees."

Sunshine hour degrees.

Plant and locality.	Latitude north.	Hours of possible sunshine.	Average daily temperature.	Sunshine hour degrees (temperature × sunshine).
Spring wheat:	° ′		° C.	
Alsace	48 30	1 996	15.0	29 900
Christiania	59 9	1 795	15.4	27 643
Halsno	59 47	2 187	13.0	28 431
Bodo	67 17	2 376	11.3	26 848
Strand	68 46	2 472	10.9	26 944
Skibotten	69 28	2 486	10.7	26 600
Barley:				
Alsace	48 30	1 416	19.0	26 900
Christiania	59 9	1 620	15.5	25 125
Halsno	59 47	2 035	11.7	23 809
Bodo	67 17	2 138	11.0	23 000
Skibotten	69 28	2 138	10.7	23 000
Do	69 28	1 824	12.7	22 876

We see that the sunshine hour degrees diminish as the latitude increases. This diminution ought to be rather more rapid in proportion as the actual state of the cloudy atmosphere approaches the theoretical state of absolute clear sky.

Thus Halsno and Bodo, localities which have very nearly the same soil, the same altitude, the same orientation, the same distance from the sea, but which are more or less under the influence of the aqueous vapor coming from the Gulf Stream, have a cloudiness during the evolution of wheat of 5.6 and 7; during that of oats, 5.4 and 7; where 0 represents perfect freedom from clouds and 10 completely covered.

If records of cloudiness could have been used, the numbers in the last column would have been computed like those in the following table:

	Possible sunshine.	Cloudiness.	Clear sky.		Average daily temperature.	Sunshine.
Spring wheat:	*Hours.*	*Tenths.*	*Per cent.*	*Hours.*	*Degrees.*	*Hours.*
Halsno	2,187	5.6	44	962	13.0	12,506
Bodo	2,376	7.0	30	713	11.3	7,865
Barley:						
Halsno	2,035	5.4	46	936	11.7	10,951
Bodo	2,138	7.0	30	641	11.0	7,051

THE SUNSHINE AND HEAT REQUIRED TO FORM CHLOROPHYLL.

After considering the preceding data Marié-Davy (1880, p. 221) presents the following as his views:

It is the chlorophyll or green coloring matter in the cells of the green leaves that alone has the property of decomposing the carbonic acid of the air. It utilizes the sunlight, but also requires a certain temperature, which may be given to it either from the air or from the sunshine itself, so that we may say that ordinarily in nature the sunshine both warms the chlorophyll by means of the red rays and enables it to decompose carbonic acid by means of the yellow rays. The decomposing action of the chlorophyll only becomes appreciable at a certain minimum temperature, which is about 15° C. when the temperature is rising. It attains its maximum activity at about 30° C., and as the temperature cools it retains an appreciable activity at about 10° C. These figures are obtained by experiments of Cloëz and Gratiolet on water plants in the full sunshine. On the other hand, Boussingault obtains 1.5° and 3.5° C. as the lower limits of temperature for the ordinary Gramineæ, but these plants were in the sunshine, and if his temperature observations had been made in the shade they would have given lower figures than these, so that undoubtedly the Gramineæ can assimilate and grow when the temperature of the air in the shade is below freezing. On the other hand, Sachs find that when the illumination is below a certain minimum, which varies with the plant and with the temperature, the color of the chlorophyll is a clearer yellow tint, and for temperatures below a certain minimum which varies with the plant it remains colorless, notwithstanding the most brilliant sunshine. Thus in 1862 the exceptionally low temperature of the month of June was sufficient to prevent the development of new leaves on the stems of maize, cucumbers, and beans, so that all these remained yellow and only became green subsequently with warmer weather and better sunshine.

The pale leaves of a sprouting bean became green in a few hours under a temperature of 30° to 33° C., but this happened only in the sunlight, for at the same temperature in the darkness they remained yellow. At a temperature of from 17° to 20° C. the greening of the leaf went on much more slowly; at 8° and 10° C. there was only a trace at the end of seven hours; below 6° C. the leaves remained fifteen days without greening.

Similarly the pale shoots of maize, even at a temperature of 24° to 35° C., did not become colored in the darkness, but in the feeble light of the interior of a room a green effect was visible at the end of an hour and a half, and at the end of seven hours the leaves were all green and of normal appearance. At a temperature between 16° and 17° C. the first traces of color were visible at the end of five hours.

But at temperatures of 13° and 14° C. nothing was seen even at the end of seven hours. At a temperature below 6° the leaves remained uncolored for fifteen days in the diffuse light of the room.

Again, the pale shoots of cabbage placed in the window, and therefore in full sunshine and at temperatures of 13° or 14° C., became green at the end of twenty-four hours; but under temperatures of 3° to 5° C. only traces of green color were seen at the end of three days, and the coloration was not complete until at the end of seven days.

Herve Mangon, by employing the electric light in place of sunlight, has arrived at similar results for rye. Marié-Davy, by the use of a single gaslight, has obtained similar results for the strawberry plant. Similarly De Candolle caused mustard and other plants to become green by the light of four argand lamps.

Evidently a very feeble light suffices to produce the greening, for the feeble individual effects accumulate and add together; but when a bright light is used secondary reactions set in, transforming and utilizing the chlorophyll itself. The light that determines the production of the chlorophyll and its green color also proceeds to destroy the chlorophyll. Thus the direct light of the sun rapidly decolors the alcoholic extract of chlorophyll, while diffuse light acts more slowly; but in a living plant the action of light is different, since it may become so intense for a special plant that the destruction of the chlorophyll may go on faster than its formation. If a green plant is carried into a dark room the chlorophyll ceases to form and a gradual process of destruction, or rather of transformation and assimilation, goes on until the plant becomes pale yellow. This mutability of chlorophyll makes it the essential medium through which the plant is nourished.

Draper, Desains, and others have shown that the chlorophyll absorbs certain rays of the spectrum; that is to say, that the work of forming and transforming chlorophyll is accomplished by means of radiations that have a certain velocity of vibration or a certain wave length, and that they are mostly those that form the red, orange, yellow, green, and blue portions of the spectrum. Awaiting a more detailed study of this phenomenon, we must at present adopt the general rule that the variation in efficiency of each of these agents is approximately proportional to the variation in the total energy of the solar radiation, although our present knowledge points to the conclusion that a radiant beam generally contains specific active wave lengths in proportions and intensities that have no necessary relation to each other.

INFLUENCE OF ABSORBENT MEDIA ON CHLOROPHYLL.

The action of sunlight on the chlorophyll within the cell is not materially modified if the light passes first through layers of cells that do not contain chlorophyll, such as those of the red colored cabbage leaf, since in those cells, as in yellow cells and others, the radiation that is absorbed is not to any extent that special radiation which the chlorophyll absorbs. The absorption of light by the yellow cells of the yellow leaves of an alder bush was examined by T. W. Engelmann (Agr. Sci., Vol. II, p. 139), who found that these absorbed most from the middle of the spectrum and least at either end, whereas the chlorophyll absorption is complementary to this. He also found that the green leaves of the alder bush, when exposed to the light side by side with the yellow leaves, set free far more oxygen than these, so that it seems probable that if the yellow cells contain only pure xanthopyll there assimilating power would be zero.

INFLUENCE ON THE SUPPLY OF SAP.

The action of sunshine in producing or altering the colors of fruits, especially the black Hamburg grape, has been experimentally studied by Laurent. (Agr. Sci., Vol. IV, p. 147.) Bunches of immature grapes quite shielded from the sunlight ripened, colored, and flavored as usual, but bunches whose food supply had been cut off by ringing the base of the stock supporting the bunch, and then also kept in the dark, remained green, small, and sour. Bunches that had been subjected to the ringing process, but which were exposed to the sunlight, produced berries of normal size, some reddish and others green and of an acid flavor. He concludes that the coloring matter of grapes may be formed in the absence of sunshine, provided a sufficient supply of nourishment be at hand, but if this supply be arrested then the color remains imperfect.

CLIMATE AND THE LOCATION OF CHLOROPHYLL CELLS.

Guntz (1886) has studied the anatomical structure of the leaves of cereals and grasses in their relations to locality and climate. This connection is infinitely complex. Among other items brought out by him we note that the green assimilating organism consists of many cells of various shapes and in most cases fills the spaces between the nerves of the leaves; in tropical grasses the green cells occur most in the inclosing sheath, but in the grasses of the steppes it lies on either side of the grooves or ridges. The intercellular gaps, according as they are larger or smaller, indicate a moist or a dry soil and, equally so, a moist or dry atmosphere. The bast in the leaves of the grasses serves primarily to strengthen the whole structure, but the bast increases with the dryness of the locality, and its proportional distribution is an appropriate, indirect indication of the climate.

THE INFLUENCE OF CLOUD AND FOG.

There are some parasitic plants, says Marié-Davy (1881 and 1882), that require only moisture and warmth in order to vegetate. They mature and propagate while entirely cut off from sunlight, but they derive this power from organic matter or cells that have been previously formed by the action of sunshine upon the plant on which the parasite itself feeds.

Similarly certain bulbous plants will flower and mature in darkness, but in doing so the bulb itself is wholly consumed and dies; the plant lives on organic matter that was elaborated and stored up by its parent and predecessor in preceding years when it had sunshine to do the work for it. If a new bulb is to be formed as a basis for the flowering of the next year then the present bulb and plant must be allowed the necessary sunlight.

Similarly the seeds of the annuals sprout and nourish their little plants out of their own substance while still beneath the surface of the earth, but when the shoots reach up to the sunshine this furnishes the energy needed for the work of assimilation and the plant begins to live on the soil and the air. The roots can only send up to the leaf an inorganic sap with possibly here and there an organic cell scattered through it which has penetrated into the roots, as it were, by accident; it is the sunshine that sets these organic cells into activity, causing them to grow and to multiply.

If a plant in vigorous growth is removed from sunshine to darkness it draws upon its own reserves and lives upon itself as long as possible. In darkness the plant transforms the organic products that are at its disposition, but it can not manufacture any new ones. On the contrary, it consumes itself and its dry weight steadily diminishes. The experiments of Boussingault on seeds, those of Sachs on plants and seeds, those of Pagnoul on the beet, and of Macagno on the grapevine all confirm this general principle. The observations of the latter show that as between two sets of vines, one exposed to the sun and the other covered with a dark cloth, the growth of the latter, as measured by the amount of solid and gaseous material, was not 10 per cent of the growth of the vine in the sunshine. Other vines under a white cloth showed a growth of 80 per cent, thus apparently proving that the differences were not due to anything else except sunshine.

Pagnoul experimented upon sugar beets, some of which were covered by glass that had been blackened on the inside; this coating of lampblack is ordinarily said to absorb heat, but it would be more proper to say that it transforms all the short waves of the sunshine into long waves so that the plants beneath it receive neither ultraviolet nor visual rays, but only the ultra-red, or long, heat weves. Therefore beneath the black glass the temperature was somewhat warmer than beneath the transparent glass and the latter warmer

than the free air. The results of analysis at the end of the experiments showed that under the transparent glass the weight of the roots was the same as in the free air, but the weight of the leaf was much more, the weight of the sugar much less, and the weight of the nitrous salts much greater. Under the black glass the weight of the roots was 4 per cent of that in the free air, and the weight of the leaves was about 25 per cent, the weight of sugar 2 per cent, and the weight of the salts 8 per cent, thus demonstrating an almost complete stoppage of the vital processes.

Evidently the action of these artificial coverings on the experimental plants is perfectly analogous to the action of cloud and fog in nature.

It is commonly said that on the seacoast the action of the salt brine blown by the wind up over the land is to stunt or prevent vegetable growth, but the same effect must be produced by the absence of sunlight in those regions where fog and cloud prevail.

INFLUENCE OF SHADE ON DEVELOPMENT.

According to Marchand (1875, p. 130), the influence of a diminution of sunlight on the development of the plant is apparent in the relative growth of plants on sunny and cloudy days or in sunny and shady places, but the matter was brought to exact measurement by Hellriegel. His experiments on barley gave him these results:

Weight of harvest of barley.

Plants raised—	Straw.	Seed.
	Pounds.	*Pounds.*
In the open air	11.44	10.10
	10.99	11.19
In a greenhouse in direct sunshine	6.72	2.86
	6.32	3.26
In a greenhouse in diffuse light only	3.40	....
	2.59	....

We see here that plants living in the greenhouse, receiving sunlight that has traversed the glass, have experienced a considerable diminution in their development as compared with those in the free air which experienced the full chemical force of the sunshine. The plants living under glass and in the diffuse light developed only a small quantity of stalk and did not perfect the seed at all.

INFLUENCE OF LONG AND SHORT WAVES OF LIGHT.

Vöchting (1887) investigated the formation of tubers as influenced especially by sunlight. Sachs had maintained that the germination was entirely prevented, or at least went on very slowly, if sunlight,

i. e., short waves, had access to the tubers. Vochting finds that, although the light does delay the growth and diminishes the distance between the tubers, still the supply of water is the important factor. (Wollny, X, p. 230.)

Sachs (1887), as the result of experiments on the effect of ultraviolet radiation upon the formation of buds, states that these rays exert on the green leaves (in addition to the assimilation produced by the yellow and neighboring rays) still another effect that consists in the development of particles that contribute to the formation of blossoms. These bud-forming particles move from the leaves into those parts of the plant where they are to bring about their own development into buds. We therefore now know of three different portions of the solar spectrum having very different physiological influences: The yellow and neighboring rays, which bring about the transformation of carbonic acid or the formation of starch; the blue and visible violet, that act as stimulants to motion; the ultraviolet rays, that produce in the green leaves the material for the formation of buds. (Wollny, X, p. 230.)

INFLUENCE OF DRYNESS AND SUNLIGHT ON DEVELOPMENT OF TUBERS.

In the climate of Germany the flowering of different varieties of potatoes is very much restricted. Only a small number of varieties flower regularly and bear fruit, whereas in Chile the plant flowers abundantly, but the tubers are small; in other words, in the Temperate Zone the formation of tubers is favored at the expense of fertilization; the energy of the one process increases while the other diminishes.

Knight and Langenthal have found that by detaching the young tubers they increase the blooming, and on the other hand, by cutting off the flowers they increase the development of the tubers, thereby largely increasing the harvest. Wollny, in 1886, experimented on four plats, each for many varieties of potatoes. He found that cutting off the flowers increased the crop of tubers as to number, size, and weight, but that something depended upon the time of cropping the flowers, which is best done a considerable time before they arrive at maturity. It seems probable that dryness and sunlight stimulate the formation of flowers, but humidity and cloudiness, at least up to a certain limit, stimulate the formation of tubers. This harmonizes with some recent results obtained by Sachs, who has shown that the ultraviolet rays stimulate the flowering. (Agr. Sci., Vol. II, p. 273.)

Chapter V.

THE METHODS OF MEASURING DIRECT OR DIFFUSE SUNSHINE AS TO INTENSITY OR DURATION.

Sunshine may be measured as to its quality or wave length, its intensity, or its duration. The methods used in measuring either of these must be understood in order to intelligently compare the published observations with phænological phenomena. The following section considers some of the methods of measuring or registering the duration or intensity of sunshine, or the intensity of the skylight, at least in so far as these have been used in agricultural studies.

THEORETICAL RELATION OF DIRECT AND DIFFUSED SUNSHINE.

The relative intensity of any radiation may be measured by its heat or light or chemical effect. The insolation received by a horizontal surface, whether directly from the sun or diffusely from the sky, is subject in a general way to calculation, but the irregularities introduced by haze and clouds can not be so calculated and must be observed daily. The following table gives, for a clear blue sky, the values obtained by Clausius for the radiation (S) that falls upon a horizontal surface directly from the sun, and in the third column the diffuse radiation (C) that falls from the whole sky upon that same surface; the total radiation (S+C) is the sum of these two. If, however, the surface is normal to the sunlight, instead of horizontal, it receives the quantity in the fifth column (I) directly from the sun, and (c) which is less than the quantity (C) from the sky, depending upon the altitude of the sun, the total being, as before, the sum of these (I+c). The study of these columns shows us the maximum and minimum amounts of sunshine that may fall upon a given leaf surface, since a leaf will in general be in some position to receive the full sunshine normally to its surface, while others will be horizontal, or vertical, or in the shade, and receive only a part of the diffuse light from the sky.

It is assumed by Radau, in his actinometry (1877), as also by Marié-Davy, that the bright and black bulb thermometers in vacuo, or the so-called "conjugate thermometers," give us the total radiation (C+I) as for the horizontal surface, and that this is the quantity in which vegetation is interested.

Relative quantities of direct and diffused sunshine.

Sun's altitude.	Horizontal surface. Sun (S).	Sky (C).	Total (S+C).	Normal surface. Sun (I).	Sky (c).	Total (I+c).
°						
10	0.03	0.07	0.10	0.19	0.04	0.23
15	.09	.09	.18	.33	.05	.38
20	.15	.11	.26	.43	.06	.49
25	.21	.13	.34	.51	.08	.59
30	.28	.14	.42	.56	.10	.66
35	.35	.15	.50	.61	.11	.72
40	.41	.16	.57	.64	.12	.76
50	.53	.17	.69	.69	.14	.83
60	.62	.18	.80	.72	.16	.88
70	.69	.18	.87	.74	.17	.91
80	.74	.18	.92	.75	.18	.93
90	.75	.19	.94	.75	.19	.94

TOTAL INSOLATION, DIRECT AND DIFFUSED.

The value of the intensity of the direct solar rays incident normally to any unit surface, as determined by the absolute actinometers of Pouillet, Violle, and others, is not so applicable to the study of the growth of plants as is the sum of the radiation from the sky and other surroundings of the plant, added to the direct solar radiation.

Comparative measures made in 1866 by Roscoe, at Manchester; Baker, at Kew; Wollkoff, on the summit of Koenigstuhl, near Heidelberg (altitude, 550 meters), and Thorpe, at Para, have given the following values of relative intensity of radiation at certain moments when the sun's altitude above the horizon was sensibly the same at all the stations. (See Marie Davy, 1882.)

Relative intensity of radiation for equal altitudes of the sun.

	Latitude.	From sun.	From sky.	Sun + sky.	Sun/sky.
	°				
Manchester	N. 53.5	0.043	0.140	0.183	0.31
Kew	N. 51.5	.150	.162	.312	0.93
Koenigstuhl	N. 49.4	.263	.174	.437	1.51
Paris	N. 48.8	.222	.501	.723	0.44
Para	S. 00.5	.136	.136	.272	1.00

At Manchester and at Paris the light that comes from the sky is more than double that which comes directly from the sun. When the sun is hidden by clouds, or even partially veiled, it is the radiation from the sky that is of the most importance to agriculture, and in any case this radiation is far from being negligible.

The Arago-Davy actinometer (believed to have been invented by Arago before 1844, but improved by Marié-Davy and used at the

observatory of Montsouris ever since 1873) is an apparatus that is intended to determine the total solar plus sky radiation that is needed in agricultural physics. A theory of the action of this instrument was devised by Marié-Davy, but the proper method of calculating its results was first developed with exactness by Ferrel, in Professional Papers of the Signal Service, No. XIII (1884), and subsequently in his Recent Advances in Meteorology (Annual Report, Chief Signal Officer, p. 373). His formula will be given on page 88.

The Arago-Davy actinometer is composed of two mercurial thermometers with very fine tubes, and having spherical reservoirs of equal dimensions, one colorless and the other covered with lampblack. In the empty space above the mercury in the thermometer tubes there is a small quantity of hydrogen or other inert gas. The small quantity of gas left in the tubes of these thermometers has no other object than to prevent the mercury from falling in the tube by the force of gravity when the bulb is turned upward toward the sky. Each thermometer is inclosed in a larger glass tube or cylinder, terminated by a spherical enlargement, in the center of which is placed the center of the bulb of the thermometer. This tube and enlargement constitute the inclosure, and it is exhausted of air as perfectly as possible. The immovability of the thermometer, relative to the walls of its inclosure, is assured by a soldering at the upper extremity of the tube and, at the opposite end toward the reservoir, by two rings of cork held by friction between the interior tube and exterior cylinder. These thermometers, with their respective glass inclosures, are turned up with their bulbs toward the sky, and by means of double clamps fixed parallel to two metallic rods, arranged in the form of a V and turned, the one toward the east, the other toward the west. These metallic rods make an angle with each other of 60°—that is to say, of 30° with the vertical—and are fastened to a support of wood or iron 1.20 or 1.30 meters in height above the earth. The support is solidly planted in the ground in an open place, remote from buildings, plants, or any other obstacle capable of intercepting the direct radiation of the sun. The two thermometers, the envelopes of which are exposed near each other, have necessarily the same temperature and mark the same degree as long as they remain in perfect darkness; but hardly does day begin to break than the thermometer with the black bulb marks a higher temperature than that with a plain glass bulb. The difference in temperature of these two thermometers gives the "actinometric degree" for the moment of observation; that is to say, it serves to measure the intensity with which the radiation strikes the two thermometers and is absorbed by the black bulb; consequently, at least approximately, it serves to measure the intensity with which the

radiation strikes the ground and neighboring plants and accumulates therein.

After three years' use of this instrument, Marié-Davy selected the observations made on the days of perfect clearness of the sky, of which there were only nine, since many days that would be called cloudless showed slight traces of haze. For these days the difference between the readings of the black bulb and bright bulb is represented closely by the exponential formula

$$t - t' = 17^\circ \times 0.875^e$$

where the exponent e represents the thickness of the layer of air through which the sun's rays must pass in order to reach the observer; this thickness, of course, increases as the sun approaches the horizon, being unity for the zenith and 10 for an altitude of 2°, as shown by the following table, which is an abstract of that used by Marié-Davy in his computations:

Thickness of the layer of air traversed by the solar rays, as computed by Lambert's formula.

Altitude of sun.	Thickness, e.	Altitude of sun.	Thickness, e.
°		°	
0	12.69	25	2.30
2	10.20	30	1.96
4	8.28	40	1.54
6	6.83	50	1.30
8	5.75	60	1.15
10	4.92	70	1.06
15	3.58	80	1.02
20	2.80	90	1.00

As the formula of Lambert has been chosen by Marié-Davy for use in connection with his form of actinometer, we have therefore given its results in the preceding table; but as the more accurate formula, as given by Laplace, has been applied to other forms of actinometers, and may even be preferred for the Arago-Davy instrument, I therefore give a table showing the thickness by the formula of Laplace as used by Violle and the value of the intensity (I) as given by Violle.

Thickness of the layer of air traversed by the direct solar rays as computed by Laplace's formula, and the corresponding value of I, the absolute intensity of direct sunshine in calòries per minute per square centimeter which fall normally on any surface through the purest air, as given by Voille.

Altitude of sun.	Thickness (e), Laplace formula.	Intensity (I) of direct sunshine, Violle.	Altitude of sun.	Thickness (e), Laplace formula.	Intensity (I) of direct sunshine, Violle.
°			°		
0	35.50	0.359	30	1.995	2.275
2	18.90	0.896	35	1.740	2.306
4	12.20	1.293	40	1.555	2.331
6	8.60	1.540	45	1.420	2.349
8	6.85	1.730	50	1.305	2.364
10	5.70	1.868	60	1.155	2.383
15	3.81	2.059	70	1.065	2.395
20	2.90	2.164	80	1.016	2.401
25	2.425	2.229	90	1.000	2.403

Observation shows that no two such Arago-Davy actinometers placed side by side will give exactly the same results; therefore the rule has been adopted of comparing all instruments with the standard kept at Montsouris, and a standardizing factor is thereby obtained by which the observed difference between the bright and black bulb of any pair is to be multiplied in order to reduce it to a common standard.

In addition to the standardizing factor of the preceding paragraph, Marié-Davy has also introduced the conception of an ideal standard actinometer, graduated in such a way that the first factor, 17° in the above-given formula as expressed in centigrade degrees, shall be represented by 100 "actinometric degrees" in his ideal instrument; that is to say, all the differences (t–t') observed with any actinometer, after being multiplied by the standardizing factor, have still to be multiplied by the factor 5.88 in order to convert them into ideal actinometric degrees. For convenience both these factors may be replaced by one, and in this way the instrument and Marié-Davy's methods have been extensively employed in studying the relation between sunshine and crops.

In such study Marié-Davy and his pupils take the "sum of the total number of actinometric degrees" as the datum for comparison with crop reports, instead of the sum of the temperatures of the air observed in the shade, or the sum of the soil temperatures as used by other investigators. If we divide the actinometric degrees given in any case by the factor 5.88 we shall obtain the excess of the black bulb over the bright bulb as originally observed in centigrade degrees. From this we can obtain the true relative quantities of solar radiation by a modification of the method given by Ferrel (pp. 41–50

of his above-quoted work of 1884, on the Temperature of the Atmosphere and the Earth's Surface).

Until such a method has been perfected (see an article by Ferrel in Am. Jour. Sci., May, 1891, 3, Vol. XLI, p. 378) we will for the present quote the actinometric degrees and other figures as ordinarily published by Marié-Davy and others; but the reader must bear in mind that these results from the hypothesis assumed by Marié-Davy that the observed difference between the bright and black bulb is proportional to and therefore a proper measure of the intensity of the radiant heat that falls upon these thermometers; a hypothesis which, as Ferrel has shown, is far from being true. The error of this hypothesis is of such a nature that for a given difference or a given actinometric degree the true intensity of radiation is greater at high temperatures than at low temperatures. Probably the recorded actinometric degrees therefore give a rather low value for the solar and sky radiation during the hottest portions of summer days.

The accompanying table, as published by Marié-Davy, shows the actinometric degrees calculated for the clearest of skies at Paris at noon of each day. They are computed according to the preceding formula, viz, A=actinometric degrees$=100\times0.875^{e}$; in which, as before said, the coefficient, 0.875, represents the penetration or the total heat which penetrates to the observer, both from the sun and the surrounding sky, and includes even that small part that is directly reflected from the surrounding grassy lawn or other surface when the sun is in the zenith; if there were no atmosphere present the total amount received would be 100. It will be less confusing if the reader will consider these so-called "actinometric degrees" as "percentages of what would be received in the absence of the atmosphere."

Columns 5, 6, and 7 of our table give the mean value of the five actinometric percentages observed on the clearest days at 6 a. m., 9 a. m., noon, 3 p. m., and 6 p. m.; in the absence of actual observations these means may be employed in our study, provided we make a proper allowance for the influence of hazy and cloudy skies. It is, however, always desirable that the actual observation of the actinometer should be available, and with it should be associated a simultaneous record of the cloud or haze as given by the sunshine recorder.

Solar radiation plus sky radiation expressed as actinometric percentages according to Marié-Davy, calculated for skies as clear as at Montsouris and for various latitudes.

Date.	Noon observation, latitude—			Mean of 5 observations daily, latitude—		
	42° N.	46° N.	50° N.	42° N.	46° N.	50° N.
January 1	73.6	69.9	65.1	38.0	34.6	30.2
January 11	74.5	71.2	66.7	39.0	35.9	31.9
January 21	75.9	72.9	69.0	40.3	37.7	34.2
February 1	77.5	75.1	71.8	42.0	39.9	37.0
February 11	79.1	77.0	74.4	43.5	41.8	39.6
February 21	80.6	78.9	76.7	45.0	43.6	41.9
March 1	81.6	80.1	78.4	46.2	44.9	43.7
March 11	82.8	81.6	80.1	49.6	48.6	47.5
March 21	83.8	82.8	81.6	55.7	55.0	54.2
April 1	84.7	83.8	82.9	60.7	60.6	60.2
April 11	85.3	84.6	83.8	65.0	65.1	65.1
April 21	85.8	85.2	84.6	68.4	68.7	68.9
May 1	86.2	85.7	85.0	71.0	71.5	71.8
May 11	86.5	86.0	85.5	73.0	73.4	73.8
May 21	86.7	86.3	85.8	74.3	74.9	75.3
June 1	86.8	86.5	86.0	75.3	75.9	76.3
June 11	86.9	86.5	86.2	75.9	76.3	76.8
June 21	87.0	86.6	86.2	76.0	76.6	77.0
July 1	86.9	86.5	86.2	75.8	76.3	76.8
July 11	86.8	86.5	86.0	75.3	75.9	76.3
July 21	86.7	86.3	85.8	74.4	75.0	75.4
August 1	86.5	86.0	85.5	73.0	73.5	73.8
August 11	86.2	85.7	85.1	71.0	71.5	71.9
August 21	85.8	85.2	84.5	68.4	68.8	69.0
September 1	85.3	84.5	83.7	64.7	64.8	64.8
September 11	84.6	83.8	82.8	60.5	60.2	59.9
September 21	83.8	82.8	81.6	55.9	55.3	54.5
October 1	82.9	81.7	80.2	49.4	48.5	47.5
October 11	81.7	80.3	78.5	46.1	45.0	43.6
October 21	80.4	78.7	76.4	44.8	43.4	41.6
November 1	78.8	76.6	73.9	43.3	41.5	39.1
November 11	77.2	74.7	71.4	41.3	39.0	36.0
November 21	75.7	72.7	68.8	40.2	37.5	34.0
December 1	74.4	71.0	66.5	38.8	35.7	31.7
December 11	73.5	69.8	65.0	37.9	34.[illegible]	30.1
December 21	73.2	69.4	64.4	37.6	34.1	29.5
January 1	73.6	69.9	65.1	38.0	34.6	30.2

THEORETICAL FORMULÆ FOR ACTINOMETER.

In reply to some criticisms of Violle, Marié-Davy (1880, p. 245) gives the only statement that I have seen of his theory or explanation of the working of his conjugate thermometers. It is about as follows: Let—

a be the absorbing power of the bright bulb.

l the absorbing power of the black bulb.

c a numerical coefficient for converting degrees of temperature into a quantity of heat.

q the quantity of radiation or heat falling per minute on the black bulb and also on the bright bulb.

$a\,q$ the quantity of radiation absorbed by the bright bulb.

$l\,q$ the quantity of radiation absorbed by the black bulb.

e the emissive power of the black bulb.

e' the emissive power of the bright bulb.

t and t' the temperatures of the black and bright bulbs, respectively, when they come to the stationary temperature that indicates equilibrium between absorption and emission.

T the temperature of the glass envelopes within which the thermometers are inclosed in a space that is an approximate vacuum.

On the assumption of the Newtonian law of radiation, viz, that the quantity of heat emitted is proportional to the excess of temperature, we have the following relations:

$$q = c\,e\ (t - T)$$
$$a\,q = c\,e'\ (t' - T)$$

From these expressions we can, by elimination of T, find the following expression for q—that is to say, the quantity of solar radiation per unit of time that is at that moment falling on the two thermometers, at least in so far as this radiation is capable of being transformed into heat by absorption into the bulbs of the thermometers:

$$q = \frac{c\,e\,e'}{e' - a\,e}(t - t')$$

Marié-Davy, in the absence of exact knowledge of these coefficients a, c, e, e', prefers to attempt to determine only relative measures of the intensity of radiation. He therefore assumes that the expression $\frac{c\,e\,e'}{e' - a\,e}$ is equal to 5.88 units, and the values for q thus obtained he calls actinometric degrees, since on the very clearest days in Paris they accord well with the assumption that the so-called solar constant of radiation is 100 actinometric degrees, and that the coefficient of transmission of sunshine through the atmosphere is 0.875.

Ferrel (1884), in his memoir on the temperature of the atmosphere (p. 41), has improved upon Marié-Davy's theory, in that he has applied to the conjugate thermometers the law of radiation, established by Dulong and Petit in 1817, which is applicable to a much larger range of temperatures than the Newtonian law adopted by Marié-Davy. Ferrel's formula may be written:

$$q = 4.584\ k\ m^{t'}\ (m^{t - t'} - 1)$$

where the notation is the same as before, except that m is the number 1.0077, as determined by Dulong and Petit and k is a factor that varies with the quality of the bright bulb, whose absolute value is

usually greater than l, but whose relative value may by preference be determined by referring each pair of conjugate thermometers to an adopted standard pair. Ferrel's formula is especially devised for thermometers having spherical bulbs, measures made by it at high and low temperatures give results that are comparable with each other; for absolute results the numerical coefficients may need some modification, but as it stands it gives the values of q approximately in calories per minute per square centimeter.

Omitting for the present the factor k in Ferrel's formula, which must be specially applied for each thermometer, we have the values of q in calories as given in the following table (see Ferrel, p. 37), which also presents the corresponding values given by the formula of Marié-Davy in actinometric degrees. In a critical study of observations reduced by these two methods we have to recall that Marié-Davy's actinometric degrees are really fractions of a calorie, or units of heat so small that 100 of them are equivalent to the absolute radiation of the sun received at the outside of an atmosphere whose coefficient of transmission is 0.875; whereas Ferrel's calories have been adopted without predicating anything as to the solar radiation or atmospheric absorption, concerning which his observations show that the solar radiation constant is between 2 and 2.25 calories per minute per square centimeter and the atmospheric coefficient of transmission to be used with the conjugate bulbs is 0.72.

Solar radiation deduced from observations with the conjugate thermometers.

$t-t'$.	Marie Davy, actinometric degrees.	Ferrel, calories per minute per square centimeter for the respective bright-bulb temperatures.								
		−10°	−5°	0°	+5°	+10°	+15°	+20°	+25°	+30°
° C.										
5	29.4	0.166	0.172	0.179	0.186	0.194	0.201	0.209	0.217	0.226
10	58.8	.339	.352	.366	.380	.395	.410	.426	.443	.460
15	88.2	.518	.538	.559	.581	.604	.627	.652	.678	.704
20	117.6	.705	.732	.761	.791	.822	.854	.887	.922	.958
25	147.0	.898	.933	.969	1.007	1.047	1.087	1.131	1.175	1.220
30	176.4	1.099	1.142	1.187	1.234	1.282	1.332	1.385	1.438	1.495
35	205.8	1.309	1.360	1.413	1.469	1.526	1.585	1.647	1.712	1.778
40	235.2	1.525	1.585	1.646	1.711	1.778	1.848	1.920	1.995	2.073
45	264.6	1.750	1.820	1.891	1.964	2.042	2.121	2.204	2.291	2.380

INTENSITY AND DURATION OF SUNSHINE AT MONTSOURIS.

In order to have at hand data that will enable one to approximately infer some of the relations between the temperature of the air and of the soil and of the solar radiation, one may consult the tables for the observations at Montsouris, given by Marié-Davy in his Annuaire for 1887.

As those who can not make use of the actinometric degrees deduced by Marié-Davy from his observations of his conjugate bulbs will necessarily have to use either the simple observations of clear sky and cloudy sky, as given by the sunshine recorder, or the equivalent personal observations of the clouds, I give the following tables, which show how nearly parallel these two phenomena may be. Evidently in our study of the influence of insolation on crops in America from year to year we may use the sunshine recorder or the ratio between the actual and the maximum possible duration of sunshine without much error, at least in the growing season.

Mean of five daily actinometric observations at Montsouris, expressed in Marié-Davy's actinometric degrees or percentages of maximum possible intensity.

Month.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.
April	44.1	40.1	36.3	35.4	28.6	38.9	33.0	39.7	36.8	34.5	34.1
May	47.7	45.8	38.7	41.5	40.6	50.3	48.9	47.4	45.9	46.3	40.3
June	46.0	48.8	54.5	47.7	45.1	41.2	53.3	47.0	45.3	43.2	46.1
July	47.3	52.1	48.6	50.6	41.2	50.0	52.0	46.6	42.2	43.4	49.4
August	39.9	42.0	43.2	37.8	42.3	39.1	40.3	34.0	39.0	36.2	36.4
September	35.7	30.9	31.4	30.9	32.7	30.2	28.3	27.1	30.5	30.8	24.1
Average	43.5	43.5	42.1	40.7	38.0	41.6	42.7	40.3	39.9	39.1	38.4

Mean of five daily observations of the cloudiness at Montsouris expressed as ratio of the actual duration of sunshine to the maximum possible duration.

Month.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.
April	0.66	0.60	0.54	0.53	0.43	0.58	0.49	0.60	0.55	0.52	0.51
May	.64	.62	.52	.56	.55	.68	.66	.64	.62	.62	.54
June	.60	.64	.71	.62	.59	.54	.70	.61	.59	.56	.60
July	.63	.69	.64	.67	.55	.66	.69	.62	.56	.57	.55
August	.57	.60	.62	.54	.61	.56	.58	.50	.56	.52	.52
September	.62	.54	.55	.54	.67	.53	.49	.47	.53	.54	.42
Average	.62	.62	.60	.58	.55	.59	.60	.57	.57	.55	.52

RELATIVE TOTAL HEAT RECEIVED FROM SUN AND SKY DURING ANY DAY, BY HORIZONTAL SURFACES.

A more accurate way of considering the amount of insolation at any locality is to compute the total radiation (expressed by its equivalent heat in calories) received by a horizontal surface in the natural daytime of that day and latitude, taking account of the absorption by the atmosphere. (See Annales Agronomique, 1878, IV, pp. 270–296, or Ann. Report Chief Signal Officer for 1881, pp. 1200–1216.) This has been done by Aymonnet by a graphic method. He assumes that if the sun were in the zenith then the unit of horizontal earth's surface would, because of atmospheric absorption, receive only 0.75 of

the heat that it would receive if it were outside the atmosphere. Of the remaining 25 per cent one-half reaches this horizontal unit by way of the diffuse reflection from the sky, so that with the sun in the zenith the unit receives 0.875 of the original solar heat. For a point on the equator during twelve hours this would amount to $0.875\times12\times60\times60$ of the total possible if the sun were in the zenith. Using this as a basal datum, Aymonnet obtains the relative numbers given in the following table or the ratio of the heat actually received during one day to that which would have been received if the sun had stood for twelve hours in the zenith. Thus on June 20, at latitude 30°, the horizontal unit receives 0.347 of that corresponding to the ideal sun in the zenith all day, while at the north pole on the same day the horizontal unit received during twenty-four hours 0.328 of what it would had the sun stood in the zenith for twelve hours. In fact the amount of heat received by horizontal surfaces is nearly uniform for all latitudes for the days June 15–July 28. These relative numbers or ratios may be turned into absolute calories by multiplying them by the so-called "solar constant," whose value is probably between two and three calories per minute per square centimeter.

Relative quantities of total heat received on specified days from the sun and sky at different latitudes by a unit surface of horizontal ground during one cloudless day, allowing for the absorption and diffuse reflection of ordinary clear air, as computed by Aymonnet.

Dates, 1874.	Declination of sun, north.	Latitude—						
		0°.	10°.	30°.	50°.	70°.	80°.	90°.
March 20	0 07	0.301	0.295	0.255	0.175	0.075	0.029	0.000
March 28	3 02	.298	.297	.268	.190	.098	.049	.017
April 7	6 52	.295	.303	.284	.215	.127	.082	.058
April 15	9 48	.292	.306	.296	.235	.157	.115	.100
April 25	13 14	.288	.307	.310	.261	.191	.159	.151
May 5	16 17	.284	.305	.322	.281	.226	.207	.205
May 15	18 54	.279	.304	.331	.298	.255	.249	.250
May 25	20 58	.274	.304	.337	.313	.282	.280	.286
June 5	22 34	.272	.303	.342	.324	.304	.312	.313
June 15	23 20	.268	.302	.346	.329	.314	.323	.326
June 19 to 23	23 27	.267	.301	.347	.330	.315	.325	.328
July 7	22 36	.272	.303	.342	.324	.304	.312	.314
July 19	20 51	.274	.304	.337	.313	.282	.279	.284
July 28	18 59	.279	.304	.331	.298	.255	.249	.251
August 7	16 25	.284	.305	.322	.281	.226	.209	.207
August 18	13 06	.288	.307	.310	.261	.191	.159	.152
August 25	10 45	.290	.307	.301	.242	.164	.128	.115
September 5	6 48	.295	.303	.284	.215	.127	.082	.058
September 15	3 00	.298	.297	.268	.190	.098	.049	.017
September 23	0 06	.301	.295	.255	.175	.075	.029	.000

RELATIVE TOTAL HEAT RECEIVED DURING CERTAIN MONTHS.

By adding the amount for each day of any month in the following table we get the relative numbers for the total amount of heat received direct from the sun at various latitudes during certain months by a unit of horizontal surface under a clear sky, and after absorption by ordinary clear air, plus the amount received from the diffuse sky light or the atmospheric reflection, all expressed in terms of the amount that unit surface would receive if the sun were constantly in the zenith during twelve hours. The coefficient of transmission through one atmosphere for zenithal sun is, as before, 0.75, and the added sky-light is 0.125, to accord with the Arago-Davy conjugate thermometers, since these are affected by the sum of the heat received by their surfaces from the sun and from the atmospheric particles in the visible celestial vault.

Relative quantities of total heat received monthly at different latitudes in the northern hemisphere.

Month.	0.	10.	30.	50.	70.	80.	90.
March 20 to 31	3.7	3.7	3.3	2.3	1.1	0.6	0.2
April	10.0	10.6	10.1	8.0	5.4	3.9	3.4
May	9.8	10.7	11.7	10.5	9.0	8.6	8.7
June	9.2	10.4	11.9	11.3	10.7	11.0	11.1
July	9.7	10.7	12.1	11.3	10.3	10.1	10.2
August	10.1	10.7	10.9	9.2	6.8	5.9	5.8
September 1 to 23	7.7	7.8	7.1	5.2	2.7	1.5	0.9
Total	60.2	64.6	67.1	57.8	46.0	41.6	40.3

PHOTO-CHEMICAL INTENSITY OF SUNSHINE.

Bunsen and Roscoe, in a series of memoirs published in the Philosophical Transactions, London, 1857, 1859, and 1863, entitled, "Photo-chemical researches," discussed the methods of measuring the chemical action of light by help of photographic tints, and endeavored to improve upon the methods of Herschel, Jordan, Claudet, and Hankel. They adopted as a standard unit for measurement that intensity of the light which in one second of time produces the standard tint of blackness upon the standard paper. Their methods are too laborious for the ordinary meteorological observer, but have furnished some important data as to the chemical activity of diffuse sunlight and of total daylight.

In his memoir of 1864, Roscoe states that he and Bunsen had developed a method of determining the chemical intensity of both direct sunlight and diffuse sunlight, or the total daylight, that is, based upon the law that the intensity of the light multiplied by the duration of exposure of chloride of silver paper of uniform sensitiveness gives a series of numbers proportional to the shades of tints,

so that light of the intensity 50, acting during time t, produces the same blackening effect as light of intensity t acting during the time 50. According to this method the chemical action of the total daylight was determined for Manchester, England, many times a day during 1864, and the total daily chemical intensity has been computed for the year August, 1863, to September, 1864. Very large changes in chemical intensity occur when the sky is cloudless and unchanged as far as the eye can perceive. The total intensity for an apparently cloudless day varies from 3.3 for December 21, 1863, to 119, June 22, 1864. This last number, compared with the figure 50.9 for June 20, and 26.6 for June 28, shows the enormous variations that take place in the chemical rays that reach the observer at Manchester on cloudless days. This variation is undoubtedly due in part to smoke and moisture, but possibly other unknown influences are also at work.

In 1867 H. E. Roscoe communicated to the Royal Society the results of work done by his method at Kew, England, in 1865, 1866, and 1867; at Heidelberg, 1862 and 1863, and at Para, Brazil, 1866. The general results are that the chemical intensity attains its maximum at noon and not, like the temperature, at some time after noon. Everywhere the intensity increases from hour to hour with the altitude of the sun, and is very closely proportional to it even when the sky is partially clouded, but of course the rate of increase varies with the season, the amount of cloud, and the degree of atmospheric opalescence. The total chemical intensity for each month, as determined from numerous observations, is as follows for Kew:

Total photochemical intensity of direct and diffuse light (Roscoe).

Month.	1865.	1866.	1867.	Month.	1865.	1866.	1867.
January	....	15	13	July	114	107	....
February	....	24	22	August	89	94	....
March	....	34	31	September	108	70	....
April	98	52	....	October	23	29	....
May	118	79	....	November	18	16	....
June	82	92	....	December	(8)	(14)	....

Roscoe compares these figures with the cloudiness, and finds that the ratio between cloudiness, expressed on a scale of 10, and the chemical intensity is as 1 to 5 in some months and as 1 to ½ in others. A similar irregularity of ratio is found when he considers the absolute moisture in the atmosphere; whence he concludes that the variations in chemical intensity, as between the spring and autumn, are not perfectly explained by either of these factors. He finds the high autumnal and low vernal intensity fairly well explained as due to the transparency or opalescence produced by finely divided solid particles or dust.

Passing from Kew to Para, it appears that the chemical action of total daylight during the month of April, 1866, at Para was 6.6 times as great as at Kew.

In order to obtain data for a clearer atmosphere, Roscoe and Thorpe conducted observations in 1867 near Lisbon, Portugal, and published their results in a memoir of 1870, where they have given the relation between the sun's altitude and the chemical intensity. The intensity is the same for hours that are equidistant from apparent noon. The relative intensity of direct sunlight, reflected sky light, and total insolation is shown for different altitudes at Lisbon by the following table:

Intensity of insolation at Lisbon for clear skies.

Mean altitude of sun.	Number of observations.	Observed chemical intensity.		
		Sun.	Sky.	Total.
°				
9.85	15	0.000	0.038	0.038
19.68	18	.023	.062	.085
31.23	22	.052	.100	.152
42.22	22	.100	.115	.215
53.15	19	.136	.126	.262
61.13	24	.195	.132	.327
64.23	11	.221	.138	.359

In general, the total intensity is directly proportional to the number of degrees of altitude. For altitudes between 18° and 35° the intensity on a plane perpendicular to the incident rays is about the same as the intensity of total sky light on a horizontal plane. The intensity of direct sunlight on a horizontal plane is equal to the intensity of total sky light on a horizontal plane when the sun's altitude is about 45°. At all altitudes of the sun below 21° the chemical action of diffuse daylight exceeds that of direct sunlight.

In their memoir of 1871 Roscoe and Thorpe determined the amount of chemical action for total sky light of a cloudy sky during totality of the solar eclipse, and found it much less than 0.003, and therefore not measurable. They found the total chemical action of the direct sunlight to be strictly proportional to the visible area of the portion of the solar disk up to a certain point in the obscuration, after which the influence of sky light is inappreciable. For altitudes below 50° at Catania, Sicily, as elsewhere, the amount of chemical action effected by diffuse daylight on a horizontal surface is greater than that exerted by the direct sunlight. At altitudes less than 10° direct sunlight is almost completely robbed of its chemically active rays.

PHOTOGRAPHIC INTENSITY OF SUNSHINE.

A photographic method of determining the brightness of sunshine or sky light is very desirable as supplementing the thermometric methods. It is as erroneous to assume that all radiation that falls upon a black-bulb thermometer is absorbed by it and converted into heat and measured by the expansion of the mercury as it is to assume that all the radiation that falls on a photographic film is absorbed by it and is represented by the chemical changes that take place in the film. Equally erroneous would it be to assume that all the radiation that enters the eye is represented by the impression of brightness conveyed by the retina to the brain. In order to measure in absolute units the total energy radiated from the sun, we need a proper summation of the thermal, visual, and photographic work done by the radiation. If we wish to determine only the intensity of that part of the radiation that does the work in which agriculture is chiefly interested we should consider only the heating effects of the radiation and the special chemical effects manifested in the action of sunlight upon chlorophyll.

The action of the sunlight upon the chlorides and bromides of silver, as in ordinary photographic processes, may not be an exact measure of its action upon the leaves of plants. Some other chemicals may be more appropriate for use at agricultural experiment stations, but the photographic methods perfected by Profs. H. W. Vogel and L. Weber are worthy of trial as a first step in the right direction. These processes give us the relative intensity of the radiations that belong to the blue end of the spectrum, with only a small admixture of the influence of green and yellow rays.

During the year 1890, as the result of a numerous series of observations at Kiel, Prof. L. Weber found that the reddish light of the spectrum on dark winter days has only about 500 times greater intensity than the quantity of light from a normal candle at a distance of 1 meter, when measured by their relative effects on a photographic plate, while at the same time the photographic intensity of the green light of the spectrum was four times as much. On bright summer days the intensity of the red light was 50,000 times that of the candle at 1 meter, while the intensity of the green light was about 200,000, or about 4 times as much in summer as in winter. The intensity of the blue light in the solar spectrum was about 25 times that of the red light, which ratio varied a little with the kind and amount of cloud. In all this photographic work a very sensitive silver bromide paper was used; so that these results, strictly speaking, relate only to the variations in the intensity of those special rays that affect this chemical. But these variations will be nearly parallel to the diurnal and annual variations of the rays that affect the growth of plants.

Further details of Weber's results are given in the German periodical, Photographische Mitteilungen, edited by Professor Vogel, at Berlin.

It is worth while to call attention to the fact that during the long twilights of northern latitudes in midsummer plants receive an appreciable quantity of the blue radiations from the sky, while receiving little or nothing of the red, or heat, rays.

MARCHAND'S SELF-REGISTERING CHEMICAL ACTINOMETER.

A convenient form of registering actinometer is that devised by Marchand (1875), which he at first called "photantitupimeter," but which name he afterwards contracted and modified to "phantupimeter." This consists of a vertical graduated tube, closed at the upper end, into which there can escape and be measured the carbonic acid gas given off by the decomposition of a mixture of solutions of perchloride of iron and oxalic acid. By the action of sunshine on this mixture, carbonic acid gas is slowly disengaged, and by its accumulation in the measuring tube gives us apparently a means of determining the sum total of the influences of the sun during any period. This apparatus was diligently employed for many years by Marchand at Fecamp, near Havre, and has afforded him many interesting results.

COMPARISON OF MARCHAND'S AND MARIE DAVY'S RESULTS.

Radau (1877), in his work on Light and Climate, states that the results given by different methods of measurement of sunshine appear to differ largely among themselves, but yet there is a certain similarity in the figures. The accompanying table shows the results of observations by Marchand's chemical method and by Marié-Davy's thermometric method, or conjugate thermometers, which latter, on account of its convenience, has been widely adopted.

Month.	Total daily chemical effect, in cubic centimeters, of carbonic acid (Fecamp, 1869-1872).	Mean daily record of actinometric degrees (Montsouris, 1872-1876).	Month.	Total daily chemical effect, in cubic centimeters, of carbonic acid (Fecamp, 1869-1872).	Mean daily record of actinometric degrees (Montsouris, 1872-1876.
January	1.84	13.0	August	18.92	41.2
February	3.93	15.6	September	13.65	31.8
March	6.44	26.0	October	6.86	20.1
April	14.10	37.5	November	2.89	12.5
May	19.46	46.2	December	1.80	9.4
June	21.04	48.2	Annual average	11.03	29.3
July	21.41	50.6			

If the atmosphere were not so very different at these two localities, we could have hoped to use the monthly ratios of these numbers for reducing similar series elsewhere to a common standard.

VIOLLE'S CONJUGATE BULBS.

The refined methods for measuring solar radiation adopted by Violle (1879) in his absolute actinometry can hardly be utilized in agricultural investigations owing to the labor of using the apparatus. But the continuous register obtained by him by means of thermo-electric apparatus is an important improvement in the methods available for comparing climates. On the other hand, Violle has suggested a modification of the conjugate thermometers which he calls his "conjugate bulbs," which is worthy of consideration, although far from being as sensitive as Marié-Davy's apparatus. These bulbs are made of thin copper, one of them blackened and the other gilded on the outside; the interiors are blackened, and the thermometer bulbs within them are also blackened. This apparatus has an apparent advantage over Marié-Davy's, in that the sunlight is not required to pass through glass before striking the thermometer. It would appear likely that with smaller bulbs (Violle uses 1 decimeter in diameter) and with more sensitive thermometers Violle's method might give better results and be worthy of recommendation to agricultural investigators. The results given by his apparatus have need to be reduced by some method based on the considerations indicated by Ferrel (1891).

BELLANI'S RADIOMETER OR VAPORIZATION ACTINOMETER.

Among the many devices invented for the purpose of obtaining, at least approximately, the sum total of the effect of sunshine received during any day by a given plant is one that has been used for a few years at the Montsouris Observatory, and is a modification of an apparatus originally devised by the Italian physicist, Angelo Bellani, which is thus described by Descroix (p. 128, Annuaire de Montsouris, 1887; see also the Annuaire for 1888, p. 206, where it is called the lucimeter, although it does not measure light properly so called).

The vaporization actinometer or the Bellani radiometer as modified at Montsouris consists of a bulb of blue glass A of about 60 mm. in diameter, inclosed within a larger bulb B of colorless glass. The space between the two bulbs is a vacuum. A is two-thirds filled with a volatile liquid and the space above it contains only its vapor, which passes through a curved tube down into a large bulb C, of clear glass, and thence down into the vertical tube D, which is graduated, and where the condensing liquid can be measured.

Under the action of the radiation from the sun and the sky the blue bulb A is warmed more than the bulb B; a distillation takes place from A and the condensed liquid is collected in the graduated tube D, where its volume is measured. This condensation in D is a source of heat, while the vaporization in A is a source of cold. The heat given off by condensation must equal that consumed in evaporation, and is drawn off from the apparatus by the action of the cool

wind blowing past C and the graduated stem D, which are shaded from the sunshine, or which may be kept immersed in melting ice, although this is not done at Montsouris. In order that the record of liquid condensed in C and D may be proportional to the heat received by A it is necessary that the volume of condensed liquid be independent of the temperature of the air and of the volume of liquid remaining in the bulb A, and be controlled only by the excess of radiant heat received by A over that received by C and D.

The comparisons that have been made at Montsouris between this Bellani radiometer and the Marié-Davy actinometer, or the so-called conjugate thermometers, show that the Bellani apparatus does not perfectly satisfy the theoretical conditions, but as it is extremely sensitive, since it distills 16 or 17 centimeters daily, and as the apparatus is not costly, Descroix has devised a formula for reducing its results to a standard. The following table gives the results of actual observations, showing the average results for the middle portion of perfectly clear days at Montsouris, near Paris, monthly during the growing seasons of 1885 and 1886. The column N shows the number of clear days; V, the volume of alcohol distilled over from 9 a. m. to 3 p. m. on these days in the Bellani apparatus; t, the average temperature of the air in the shade; T_1, the average temperature of the black bulb thermometer in vacuum in the sunshine; T_2, average temperature of the bright-bulb thermometer in vacuum in the sunshine; $T_1 - T_2$ is the average difference of these conjugate thermometers at midday; R, total illumination from the sky at midday, expressed in Marié-Davy's actinometric percentages or degrees.

Comparison of actinometric results for perfectly clear days at Montsouris, near Paris, by the Bellani radiometer and by the Arago-Davy actinometer.

Month.	N.	Bellani.		Arago-Davy at noon.			
		V.	t.	T_1.	T_2.	T_1-T_2.	R.
1885.		*ccm.*	°C.	°C.	°C.	°C.	
March	6	9.6	5.9	25.9	15.0	10.9	76.9
April	6	10.4	18.4	38.5	27.5	11.0	70.2
May	2	10.2	22.6	44.2	32.9	11.3	67.1
June	10	10.7	22.8	45.6	33.7	11.9	71.5
July	15	11.6	24.7	46.2	34.4	11.8	73.9
August	8	10.7	20.0	39.9	29.2	10.7	73.2
September	3	11.0	23.4	43.0	32.1	10.9	73.2
October	2	7.2	12.1	29.5	4.1	8.4	72.0
1886.							
March	8	11.9	1.6	22.5	11.0	11.5	77.2
April	7	12.3	17.6	36.7	26.8	9.9	74.1
May	9	12.9	15.6	38.7	25.9	12.4	76.6
June	2	12.1	19.5	42.7	30.2	10.2	75.2
July	10	12.5	23.2	44.4	32.9	11.5	72.0
August	7	12.1	22.9	41.8	31.3	10.5	68.6
September	11	11.7	21.0	38.8	28.9	9.9	69.2
October	4	10.1	19.3	35.9	26.6	9.3	71.2

Notwithstanding the simplicity of Bellani's apparatus and the ingenuity of the idea embodied therein it is evident that it needs an important modification, viz, the evaporation and condensation should

be absolutely independent of the temperature of the air and the velocity of the wind, as well as of the quantity of liquid in the bulb A, and should depend wholly on the heat received from the sun and sky. In its present form it can not be recommended as a simple means of measuring the daily sum total of radiation from the sun and sky. A second and improved form of Bellani's apparatus has been brought out under the title "Vaporization lucimeter" (see Marié-Davy, Annuaire, 1888, p. 207), but further improvements are necessary, especially the maintenance of a uniform constant temperature in the condensation bulb and tube, as, for instance, by immersing both in a bath at melting point of ice.

ARAGO'S CYANOMETER AND DESAINS' THERMO-ELECTRIC ACTINOMETER.

Other methods of observing the condition of the sky and solar radiation have been devised by physicists. Thus the cyanometer of Arago, especially in the modified form made by Dubosc, of Paris, or the thermo-electric actinometer of Desains (both of which are in occasional use at Montsouris) give useful indications. The cyanometer gives the blueness of the sky, which is largely dependent on the number and size of the particles of moisture, while the actinometer gives the quantity of heat that penetrates directly from the sun through this moist air to the ground. These instruments are complementary to each other, but can only give good results in the hands of those accustomed to the use of delicate apparatus. They serve as checks upon the records of the Arago-Davy actinometer, which latter has been made by Richard in such form as to keep a continuous register. Thus during the years 1879–1886 the Arago-Davy instruments, both in France and in India, showed a steady, progressive diminution in the intensity of the solar radiation received at the ground, followed, however, by a recovery, subsequently, which is not likely to have been due to any instrumental peculiarity. This peculiar fluctuation may have had its cause either in the sun or in the earth's atmosphere.[a]

DURATION OF SUNSHINE.

Those who can not undertake the labor of observing the heating or chemical effects of the solar radiation can easily keep a photographic register of the number of hours of sunshine, as in the apparatus devised by Jordan, of England, and modified by Marvin for use at Signal Service stations, or can keep a record of the hours of full hot sunshine, as in the Campbell, or Campbell-Stokes, sunshine recorder used in Canada. The Marvin photographic sunshine reg-

[a] This paragraph, written in 1891, is of special interest in connection with the general interest in the subject awakened in 1903 by the observations of Kimball, Dufour, and Abbott.

ister has been established at 20 Signal Service stations, the list of which is given in our tabular data. This tabular matter is omitted from this present edition, and these records will undoubtedly be so fully published as to be available to the student. Such photographic sunshine records are complementary to the ordinary record of cloudiness and of personal observations of the area apparently covered by clouds. But as the photographic register, strictly speaking, records only the cloudy condition of the sky in the immediate location of the disc of the sun, while personal estimates of the amount of cloudiness refer to the whole sky (above an altitude of 15°, 30°, or 60°, according to the various rules adopted by observers), therefore there is room for quite a discrepancy between the personal and the photographic record, and it is still a question as to which is more appropriate for agricultural study.[a]

In order to know the cloudiness, sunshine, and rainfall at a few stations representative of the district in which cereals are grown in America, I have added to the stations in the United States, which will be published by the Signal Service, the following table for 1887 compiled for Winnipeg, Manitoba (lat. N. 49° 40′, long. W. 97° 10′), from the data published by Carpmael (1890), from whose report other records may be obtained.

Sunshine and climate of Winnipeg.

Month (1887).	Rainfall.		Average cloudiness.	Average duration of sunshine per hour in percentage of total possible.							
	Inches.	Number of days.		5 a.m.	6 a.m.	7 a.m.	8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 m.
			P. ct.								
January	0.00	0	40	......	......	......	2	40	54	71	70
February	T.	1	42	......	......	11	30	58	61	67	70
March	T.	1	50	......	......	12	48	55	55	54	54
April	0.25	4	51	......	15	32	44	57	64	65	70
May	3.01	13	54	3	29	53	53	55	59	65	59
June	2.94	12	50	30	45	57	57	60	62	78	74
July	1.98	13	54	20	55	63	67	68	66	74	78
August	1.49	15	51	......	15	42	59	67	73	72	71
September	1.77	12	43	......	8	17	57	71	71	68	71
October	0.25	4	57	......	......	......	28	48	44	48	52
November	T.	1	50	......	......	......	5	29	48	60	51
December	T.	1	65	......	......	......	......	11	26	42	43

[a] Elaborate comparisons of these records were published from month to month in the Monthly Weather Review during 1892–1897.

Sunshine and climate of Winnipeg—Continued.

Month (1887).	Average duration of sunshine per hour in percentage of total possible.								Temperature.		
	1 p. m.	2 p. m.	3 p. m.	4 p. m.	5 p. m.	6 p. m.	7 p. m.	8 p. m.	Maximum.	Minimum.	Mean.
									°*F.*	°*F.*	°*F.*
January	63	54	60	31	0	......	......	......	23.2	−42.7	−14.5
February	70	66	64	49	20	1	......	......	24.8	−38.7	− 8.0
March	55	56	57	57	48	8	0	......	43.0	−36.5	11.7
April	63	62	64	59	49	35	13	......	74.8	− 9.0	37.3
May	56	57	41	47	49	53	41	5	90.6	29.0	57.2
June	84	73	69	59	67	63	48	18	88.0	33.3	64.6
July	75	76	72	64	71	68	59	29	93.2	39.0	66.5
August	70	70	71	71	60	58	30	5	88.0	33.3	61.0
September	76	75	72	70	38	10	5	......	83.8	23.2	53.8
October	60	62	57	44	18	......	......	......	64.0	− 2.8	32.4
November	50	49	48	51	14	......	......	......	58.6	−31.4	17.4
December	54	55	44	23	......	......	......	......	38.0	−41.7	− 0.3

In the above table the records of sunshine are, of course, given by the self-registering method and relate to duration of visibility of sun at the station, while the cloudiness is the average of the observer's estimates of area of sky covered.

TOTAL POSSIBLE DURATION OF SUNSHINE BY DECADES.

Tables showing the times of sunrise and sunset, or the resulting length of the day, are given is publications accessible to American readers, as follows: Meech, 1855, pages 57, 58, calculated especially for the year 1853; Schott, 1876, pages 117–119, computed for an average year and for the actual sunrise and sunset and for each degree of latitude; the Smithsonian Meteorological and Physical Tables, fourth edition, 1884, give a very convenient table on pages 711–720, by Prof. W. Libbey, computed with the declinations for Greenwich mean noon for 1862; elaborate general tables are given in the International Meteorological Tables, Paris, 1890, but they are not so convenient for our use as the Smithsonian tables or those of Schott.

By means of these tables of sunrise and sunset I have computed the accompanying table, showing the sum total of the possible sunshine expressed in hours from the beginning of January up to any date in a common year or a leap year.[a] From this table has been made up the column of maximum sunshine in the tables of meteorological results for 1879 at twenty stations in the United States as given in Section II for comparison with the crops of that year, as reported in the United States census for 1880.[b] In the absence of any other data

[a] The annual sums for December 31 in the table are about one-third to one-half per cent smaller than the figures given in the Weather Bureau table of 1905.

[b] All these manuscript statistical tables are omitted in the present edition.

one may multiply the duration of sunshine by the percentage of observed clearness and obtain the duration of sunshine for a special station. But this will give us a value that is greater or less than the value of the true intensity of sunshine according as the cloudiness occurs mostly in the morning and evening or in the midday hours. The only method for obtaining a satisfactory value of the intensity of radiation as coming direct from the sun or as reflected from the sky, the clouds, and the earth, is to maintain a self-registering actinometer or, in place of that, frequent daily observations.

In these tables I have adopted the division of each month into three parts, as done by Libbey and occasionally used by meteorologists, but the system of pentades, used by Dove, is often preferable; however, this present system is convenient for monthly summations, and is also used in the climatic table of Section II.[a]

Sums total of possible duration of sunshine, in hours, from January 1 up to any day of the year.

Interval.	Number of days.	Latitude.						
		24°.	26°.	28°.	30°.	32°.	34°.	36°.
		Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
January 1-10	10	106.7	105.4	104.0	102.5	101.0	99.4	97.7
January 11-20	10	214.5	212.0	209.3	206.4	203.5	200.4	197.2
January 21-31	11	334.7	331.0	327.1	322.9	318.7	314.2	309.5
February 1-10	10	446.0	441.4	436.6	431.4	426.2	420.6	414.9
February 11-20	10	559.4	554.1	548.6	542.6	536.7	530.2	523.7
February 21-28	8	649.9	645.2	640.3	633.9	627.6	620.6	613.6
March 1-10	10	767.4	762.4	757.2	750.5	743.8	736.4	729.0
March 11-20	10	887.2	882.1	876.8	870.0	863.2	855.7	848.2
March 21-31	11	1,021.7	1,016.8	1,011.7	1,005.0	998.4	991.1	983.7
April 1-10	10	1,146.4	1,141.9	1,137.2	1,130.9	1,124.7	1,117.9	1,110.9
April 11-20	10	1,273.3	1,269.4	1,265.3	1,259.7	1,254.2	1,248.1	1,241.8
April 21-30	10	1,402.3	1,399.2	1,396.0	1,391.3	1,386.7	1,381.5	1,376.2
May 1-10	10	1,533.3	1,531.2	1,529.0	1,525.4	1,521.9	1,517.9	1,513.8
May 11-20	10	1,666.0	1,665.1	1,664.1	1,661.8	1,659.6	1,657.0	1,654.3
May 21-31	11	1,813.6	1,814.1	1,814.6	1,813.8	1,813.2	1,812.4	1,811.4
June 1-10	10	1,948.8	1,950.7	1,952.7	1,953.4	1,954.4	1,955.3	1,956.0
June 11-20	10	2,084.5	2,087.9	2,091.4	2,093.7	2,096.3	2,099.0	2,101.5
June 21-30	10	2,220.2	2,225.1	2,230.1	2,234.0	2,238.2	2,242.7	2,247.0
July 1-10	10	2,355.4	2,361.7	2,368.2	2,373.6	2,379.4	2,385.6	2,391.6
July 11-20	10	2,489.7	2,497.3	2,505.2	2,512.0	2,519.3	2,527.1	2,534.7
July 21-31	11	2,636.0	2,644.9	2,654.1	2,662.3	2,671.0	2,680.4	2,689.6
August 1-10	10	2,767.1	2,777.1	2,787.3	2,796.6	2,806.4	2,817.0	2,827.5
August 11-20	10	2,896.3	2,907.1	2,918.1	2,928.3	2,939.0	2,950.6	2,962.1
August 21-31	11	3,036.1	3,047.5	3,059.2	3,070.2	3,081.7	3,094.1	3,106.4
September 1-10	10	3,160.8	3,172.6	3,184.7	3,196.1	3,208.0	3,220.9	3,233.6
September 11-20	10	3,283.2	3,295.2	3,307.4	3,319.0	3,331.1	3,344.2	3,357.1
September 21-30	10	3,403.3	3,415.2	3,427.4	3,439.0	3,451.0	3,464.0	3,476.9
October 1-10	10	3,521.1	3,532.7	3,544.6	3,555.9	3,567.6	3,580.2	3,592.8
October 11-20	10	3,636.6	3,647.7	3,659.1	3,669.9	3,681.0	3,693.0	3,705.0
October 21-31	11	3,761.2	3,771.5	3,782.1	3,792.1	3,802.3	3,813.4	3,824.5
November 1-10	10	3,872.3	3,881.7	3,891.3	3,900.3	3,909.4	3,919.4	3,929.4

[a] Omitted.

Sum total of possible duration of sunshine, in hours, from January 1 up to any day of the year—Continued.

Interval.	Number of days.	Latitude. 24°.	26°.	28°.	30°.	32°.	34°.	36°.
		Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
November 11-20	10	3,981.5	3,989.8	3,999.3	4,006.1	4,014.0	4,022.7	4,031.4
November 21-30	10	4,089.3	4,096.2	4,104.3	4,109.9	4,116.5	4,123.7	4,130.9
December 1-10	10	4,196.0	4,201.6	4,208.3	4,212.4	4,217.5	4,223.1	4,228.6
December 11-20	10	4,302.2	4,306.4	4,311.6	4,314.1	4,317.6	4,321.5	4,325.3
December 21-31	11	4,418.9	4,421.5	4,425.1	4,425.9	4,427.7	4,429.7	4 431.6
For leap year add to all numbers after February 28	....	11.3	11.4	11.5	11.5	11.4	11.3	11.2
January 1—December 31, 1905	....	4,436.5	4,438.1	1,439.9	4,441.1	4,444.6	4,445.8	4,448.6

Interval.	Number of days.	Latitude. 38°.	40°.	42°.	44°.	46°.	48°.	50°.
		Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
January 1-10	10	95.8	94.0	91.9	89.8	87.4	84.8	82.0
January 11-20	10	193.6	190.2	186.2	182.1	177.5	172.6	167.2
January 21-31	11	304.2	299.2	293.4	287.5	280.8	273.6	265.8
February 1-10	10	408.4	402.2	395.1	387.8	379.6	370.7	361.1
February 11-20	10	516.3	509.2	501.1	492.7	483.3	473.2	462.3
February 21-28	8	605.7	598.2	589.5	580.5	570.5	559.7	548.1
March 1-10	10	720.7	712.8	703.7	694.2	683.7	672.4	660.2
March 11-20	10	839.8	831.8	822.6	813.0	802.4	791.0	778.7
March 21-31	11	975.4	967.6	958.7	949.3	938.9	927.8	915.9
April 1-10	10	1,103.2	1,095.9	1,087.5	1,078.7	1,062.0	1,058.6	1,047.5
April 11-20	10	1,234.9	1,228.4	1,220.9	1,213.0	1,204.3	1,195.0	1,185.1
April 21-30	10	1,370.4	1,365.0	1,358.7	1,352.0	1,344.6	1,336.8	1,328.5
May 1-10	10	1,509.3	1,505.3	1,500.5	1,495.4	1,489.7	1,483.7	1,477.4
May 11-20	10	1,651.3	1,648.9	1,645.9	1,642.6	1,639.0	1,635.2	1,631.3
May 21-31	11	1,810.3	1,809.9	1,809.0	1,808.0	1,807.0	1,805.9	1,805.1
June 1-10	10	1,956.9	1,958.4	1,959.7	1,961.0	1,962.5	1,964.1	1,966.3
June 11-20	10	2,104.4	2,107.9	2,111.4	2,115.1	2,119.2	2,123.7	2,129.1
June 21-30	10	2,251.9	2,257.4	2,263.2	2,269.3	2,276.0	2,283.4	2,292.0
July 1-10	10	2,398.5	2,406.0	2,413.9	2,422.3	2,431.5	2,441.7	2,453.4
July 11-20	10	2,543.4	2,552.7	2,564.6	2,573.2	2,584.7	2,597.4	2,611.9
July 21-31	11	2,700.1	2,711.2	2,725.1	2,735.8	2,7[illegible]9.6	2,764.7	2,782.0
August 1-10	10	2,839.3	2,851.7	2,867.1	2,879.4	2,894.9	2,911.9	2,931.3
August 11-20	10	2,975.0	2,988.5	3,005.1	3,018.8	3,035.7	3,054.2	3,075.2
August 21-31	11	3,120.2	3,134.7	3,152.3	3,167.0	3,185.0	3,204.8	3,227.2
September 1-10	10	3,248.0	3,263.0	3,281.1	3,296.5	3,315.1	3,335.6	3,358.8
September 11-20	10	3,371.8	3,387.0	3,405.3	3,421.0	3,439.9	5,460.7	3,484.2
September 21-30	10	3,491.5	3,506.6	3,524.9	3,540.5	3,559.3	3,570.0	3,603.4
October 1-10	10	3,607.1	3,621.8	3,639.7	3,654.9	3,673.3	3,693.5	3,716.4
October 11-20	10	3,718.7	3,732.7	3,749.9	3,764.4	3,782.0	3,801.3	3,823.2
October 21-31	11	3,837.2	3,850.2	3,866.3	3,879.6	3,895.9	3,913.7	3,934.2
November 1-10	10	3,940.9	3,952.7	3,967.5	3,979.3	3,994.1	4,010.2	4,028.9
November 11-20	10	4,041.4	4,051.7	4,064.8	4,074.9	4,087.9	4,101.9	4,118.3
November 21-30	10	4,139.2	4,147.8	4,159.0	4,167.1	4,178.0	4,189.6	4,203.5
December 1-10	10	4,235.0	4,241.8	4,251.0	4,256.9	4,265.3	4,274.4	4,285.5
December 11-20	10	4,329.8	4,334.7	4,341.7	4,345.3	4,351.2	4,357.6	4,365.7
December 21-31	11	4,434.0	4,436.8	4,441.4	4,442.5	4,445.7	4,449.0	4,453.8
For leap year add to all numbers after February 28	....	11.2	11.1	11.0	11.0	10.9	10.8	10.8
January 1—December 31, 1905	....	4,451.5	4,454.3	4,457.4	4,461.5	4,465.7	4,470.8	4,476.7

Chapter VI.

MOISTURE OF THE SOIL.

IN GENERAL.

The soil receives its water supply either by natural rainfall or by irrigation. The plant in successive generations of cultivation adapts itself to the ordinary supply of water, but in order to perpetuate its kind it must have sufficient during the growing season to serve it as a medium for extracting from the soil and air the nutritious substances needed by it for its own development. The water really available to the plant is principally that which is left in the soil close to the roots after the surface drainage has carried off a large per cent of the original rainfall and after the evaporation by the dry wind has taken 20 per cent of the remainder from the surface soil and after a further large per cent of the remainder has by percolation or seepage slowly settled down beyond the reach of the roots of the plant. Thus it happens that the roots rarely have left for their use 20 per cent of the original rainfall, and this is the so-called "useful remainder." Generally this remainder is best expressed as a percentage of what the soil would hold were it completely saturated. Therefore its absolute quantity will vary with the character of different soils

EVAPORATION FROM THE SURFACE OF FRESH WATER.

MONTSOURIS DATA FROM DESCROIX.

An approximate idea of the relation between the velocity of the wind, its temperature, and its dryness, on the one hand, and its power to evaporate water on the other, may be obtained by collating the data given by Descroix in his article on "The climatology of Paris," in the Montsouris Annuaire, 1890, page 121. From the mass of data given by him I select the averages taken according to the direction of the wind, or wind roses, for the three summer months June, July, and August, 1889, as these are the months during which crops are liable to suffer the most severely from droughts and dry winds. I give them in the following table:

Summer wind roses of evaporation at Montsouris.

Wind. Direction.	Number of days.	Hourly velocity.	Average daily temperature.	Daily minima of relative humidity.	Evaporation daily.	Total rainfall.
		Sec. kilo.	° C.	Per cent.	mm.	mm.
From north	8	12.8	18.24	45.9	6.35	0.0
From northeast	8	14.6	19.02	46.4	5.71	4.4
From east	5	10.1	20.54	45.4	4.72	0.0
From southeast	4	7.2	20.08	47.8	4.15	0.0
From south	10	11.0	19.71	55.2	2.87	45.8
From southwest	20	15.4	18.72	51.9	3.54	39.3
From west	20	14.2	17.21	50.8	3.60	23.8
From northwest	12	11.2	17.00	51.3	3.70	10.4
Various	5	14.8	17.76	46.6	3.17	0.7
Three months	92					124.4

We see that the driest winds, or those whose relative humidity is small, such as the north and east winds, give a large evaporation, and that the velocity and temperature of the west winds, which are a little less than those of the southwest winds, does not compensate for the dryness, which latter enables them to evaporate a little less than the southwest winds.

By multiplying the average daily evaporation by the number of days we obtain the total evaporation from the saturated paper of the Piche instrument. This exceeds the total rainfall, but we are not to infer that the evaporation from ground and leaves must also necessarily exceed the rainfall, although this is generally true for the summer season.

BOSTON DATA FROM E. J. FITZGERALD.

The evaporation of the water from leaves and from the ground depends upon the temperature, wind, and humidity of the air. It is a rather complex result; if the above-mentioned elements remain constant for any time at the surface of the mass of water the evaporation from that surface will be closely represented by the following formula which is due to Fitzgerald, of Boston,

$$E=0.0166\ (P-p)\ (1+\tfrac{1}{2}\ W),$$

where W is the velocity of the wind in miles per hour; P the tension of vapor in inches of mercury corresponding to the temperature of the water; p is the tension of vapor corresponding to the dew point in the free air; E is the evaporation expressed in inches of depth of water evaporated per hour under atmospheric pressure between 29 and 31 inches of the barometer.

The evaporation from leaves and soils is usually less than that from water about in the proportion in which the soil approximates its

state of maximum saturation, or in proportion as the leaf can transpire moisture through its cell walls.

Therefore any observations of evaporation that we may make for comparative purposes can give us only the relative evaporating power of the wind and not the absolute evaporation from plants and soils.

THE PICHE EVAPORIMETER.

The simplest apparatus for observing evaporation is that known as the Piche evaporimeter. This consists of a glass tube closed at the top and hung in a free exposure; the tube is less than half an inch in diameter and filled with water; its lower open end is closed by a horizontal disk of bibulous paper about twice the diameter of the tube; the water evaporated from this paper is supplied from within the tube. The observer has simply to read the height of the water in the tube as it slowly descends hour by hour. The number so read off is easily converted into one that expresses the depth of water evaporated per hour from unit surface.

The following table from Montsouris Annuaire, 1888, page 254, shows the average evaporation thus determined by an instrument placed in the shade, also the corresponding temperatures and other data, as observed at Montsouris during thirteen years.

Evaporation at Montsouris.

[Averages for 1873–1885.]

Month.	Number of days.	Temperature of air in shade.	Tension of vapor in air.	Relative humidity.	Hourly velocity of wind.	Hourly evaporation.
		°C.	mm.	Per cent.	Kilom.	mm.
January	164	3.6	4.8	80.9	15.9	0.084
February	203	6.0	5.4	77.0	16.1	.101
March	281	9.1	5.4	62.9	17.8	.187
April	324	12.7	6.3	57.3	17.6	.225
May	341	16.2	7.4	54.0	17.5	.257
June	330	20.0	10.1	58.2	15.3	.282
July	341	22.0	11.1	56.5	14.7	.254
August	341	21.6	11.4	59.4	15.7	.234
September	330	17.6	10.2	68.0	14.4	.154
October	340	12.5	8.0	73.8	15.4	.099
November	284	8.0	6.2	77.5	18.1	.091
December	219	3.6	4.9	82.4	15.6	.063

THOMAS RUSSELL'S OBSERVATIONS.

Prof. Thomas Russell, of the Signal Office, has published results of some observations on the effect of the wind on the evaporation from the disks of the Piche evaporimeter. (See Annual Report Chief Signal Officer, 1888, p. 176, or Monthly Weather Review, 1888,

p. 235.) He finds that with the temperature of the air 84° F. and a relative humidity 50 per cent the evaporation varies with the velocity of the wind at the surface of the moist disk as in the following paragraph:

INFLUENCE OF THE WIND ON EVAPORATION.

At 5 miles an hour the evaporation is 2.2 times that in a calm; at 10 miles, 3.8 times; at 15 miles, 4.9 times; at 20 miles, 5.7 times; at 25 miles, 6.1 times; at 30 miles, 6.3 times.

The observations of the Piche instruments, as exposed in Signal Service shelters at 18 different stations, gave the results in the table following. (See Monthly Weather Review, September, 1888, p. 236.) The readings on the scale of the Piche instrument have been converted into depths of water that would be evaporated from a free surface of water within the same instrument shelter during the respective months by multiplying them by the constant coefficient 1.33, so that the evaporations here given in inches of depth of water correspond entirely to the ordinary methods of measuring rainfall.

Evaporation, in inches, observed with Piche instruments within the Signal Service thermometer shelters in 1888.

Station.	June.	July.	August.	September.
	Inches.	*Inches.*	*Inches.*	*Inches.*
Boston	5.16	5.87	5.28	2.68
New York	4.49	5.36	4.14	2.88
Washington	4.64	5.27	4.22	2.52
Buffalo	....	....	....	3.70
Cincinnati	6.22	6.93	5.36	5.33
Memphis	5.33	5.24	4.57	3.86
New Orleans	3.82	9.38	7.96	3.70
Chicago	5.59	5.52	6.97	5.79
St. Louis	6.18	5.79	4.41	4.61
Keeler	11.66	12.76	12.69	10.95
Yuma	13.86	13.63	12.88	10.36
El Paso	13.91	9.89	11.54	10.00
Dodge City	7.80	8.20	6.22	6.07
San Antonio	2.76	5.08	5.36	3.66
Omaha	7.01	6.62	5.44	6.78
Denver	9.42	10.91	8.55	5.94
St. Vincent	5.63	4.33	5.97	....
Helena	4.88	8.20	7.80	6.86
Boise City	5.83	9.14	7.68	(a)

[a] In October at Boise City the evaporation was 7.60 inches.

Professor Russell has also devised the following very satisfactory formula connecting the total daily evaporation in inches with the meteorological elements on which it depends, viz, the vapor tensions, p_w for mean wet bulb and p_d for mean dew-point temperatures, (b) barometric pressure, by means of which he has been able to compute

the possibilities of evaporation within Signal Service shelters over the whole country for an average wind velocity.

$$\text{Daily evaporation} = \frac{30}{b}\left[\,1.96\,p_w + 43.9\,(p_w - p_d)\,\right]$$

His results in this respect are platted on chart No. VI of the Monthly Weather Review, September, 1888, and show that the total annual depth of evaporation has its maximum of over 90 inches in southern Arizona, California, and New Mexico, whence it diminishes to a minimum of 20 inches annually in the northwest corner of the State of Washington and thence eastward to Maine. These figures, like his formula, take no account of the wind, because within the Signal Service shelters the wind is reduced to a velocity far less than that in the open air. These figures, therefore, represent the evaporation in open air only when there is no wind above some small limit—say 6 miles per hour but may be adapted to strong winds by the use of the figures given in the first paragraph of this section.

CULTIVATION DIMINISHES SURFACE-SOIL EVAPORATION.

The general effect of cultivation is to pulverize the upper soil; this protects the capillary roots from surface exposure, it breaks up the capillary outlets of the moisture in the soil, checks the natural evaporation that goes on at the surface, and thus preserves the water within the soil for the use of the plants. Dr. E. L. Sturtevant's observations show that the extent to which the water is thus conserved by cultivation during the months from May to September, 1885, at Geneva, N. Y., may be thus expressed: With a rainfall of 14.42 inches the cultivated soil evaporated 1.4 inches less than the uncultivated naked soil and 2.25 inches less than the soil covered with sod. In other words, the efficiency of the soil to retain useful water is increased by cultivation to an extent equivalent to 10 per cent of the rainfall. If the capillary connections between the soil in the neighborhood of the roots and the supply of moisture lower down be broken no supply of moisture can come up from below, but if the soil be well rolled the compacting will aid the capillary attraction and the plants will secure moisture from below. Again, when weeds are allowed to grow freely the injury to the crops is not due to robbing the soil of nutrition nor to their shading the ground, but principally to their robbing the soil of its moisture. Those who can with impunity allow weeds to grow must have soils containing an excessive moisture, which they thus get rid of, while those who have a comparatively dry soil must destroy the weeds in order to reserve moisture for the use of their crops. (Agr. Sci., Vol. I, p. 216.)

PERCOLATION.

The permeation of water through soils of different qualities has been studied by Welitschkowsky (Wollny, 1888, X, p. 203.) He maintained a layer of water at a constant height above the material through which it permeated; therefore the pressure forcing the water through was constant. He found that the quantity of flow increased at first rapidly, then slowly for several days, depending on the thickness of the stratum of soil and the pressure of the water, until the permeation reached the maximum; then the rate of flow diminished slightly for a day or two until it became constant. He found that the quantity of water delivered in a unit of time has no simple relation to the pressure forcing it through the soil or to the thickness of the layer of soil through which it flows, but the relation is more nearly expressed as follows: If the pressure be increased by regular additions the flow of water increases in an arithmetical progression such that the quantity equals (A) plus a constant factor (D) times the pressure (P) less unity; $A+D\ (P-1)$. The numerical values of these terms can be deduced from his extensive tables of experiments, of which the following table is an abstract:

Soil.	Size of grains.	Maximum capacity for water.[a]	Intensity of flow, in liters, per minute.					
			Layer of soil 50 cm. thick.			Layer of soil 100 cm. thick.		
			Head of water pressure.			Head of water pressure.		
			10 cm.	50 cm.	100 cm.	10 cm.	50 cm.	100 cm.
	mm.							
Fine sand	0.33	90.86	0.00013	0.00022	0.00031	....	....	....
Average sand	0.33-1.0	71.46	0.106	0.179	0.273	0.096	0.126	0.167
Coarse sand	1.0 -2.0	52.59	1.172	1.886	2.776	1.011	1.349	1.789
Small gravel	2.0 -4.0	19.37	6.747	9.594	13.137	6.435	8.034	10.015
Average gravel	4.0 -7.0	13.44	11.703	16.347	....	11.015	13.555	....

[a] The capacity for water is expressed as a percentage of the weight of the dry soil.

The general laws of the flow of waters through soils of different natures have been elaborately investigated by Milton Whitney in a series of papers published in Agricultural Science, Volume IV, to which the reader must refer for the details.

The percolation of water through the soil, whether it goes downward as drainage or upward to be evaporated from the surface, depends not merely upon the degree of comminution of the soil and its compactness, but also, among other things, to a slight extent, upon the barometric pressure of the atmosphere, so that a falling barometer is, according to E. S. Goff, generally accompanied by a corresponding increase in the rate of drainage or of percolation downward. (Agr. Sci., Vol. I, p. 173.)

AVAILABLE MOISTURE.

In his investigations as to the relation of atmospheric precipitation, especially rainfall, to the plants and the soil, Wollny shows that the percentage of water in the layer of soil containing growing plants increases from above downward as soon as the downward movement of the rain water in the soil ceases, but that the percentage increases from below upward while the rain is falling and so long as the water continues to be penetrating downward. The frequency of rainfall is of even greater importance than the quantity. Slight rainfalls that only wet the soil to the depth of a few millimeters do but little good to the vegetation, because the greater part of the water is quickly evaporated back again into the atmosphere. If it should rain daily 2 millimeters during the three summer months, then, even with this abundant precipitation the plants might die for want of water, whereas if this total of 180 millimeters were uniformly divided into ten or twelve rains during the three summer months it would be considered a remarkably favorable growing season, since under these conditions the earth would be wet down to a considerable depth and the water thus stored up is protected from evaporation. Therefore, for equal quantities of rain its value for agriculture increases as the number of rainy days diminishes, and diminishes as the number of rainy days increases, at least up to a limit that varies with the character of the soil.

In order to attain precise ideas on this subject, Haberlandt set out a series of glass tubes full of dry earth; each received at the beginning a certain quantity of water, and by weighing these from day to day he determined the loss due to evaporation. These losses are given in the following table, in percentages of the original quantity of water, which latter may be considered as a rainfall whose depth is given at the top of the column:

Date.	1.	2.	3.	4.	5.	6.
Initial rainfall September 20 in millimeters	2.22	6.67	13.33	26.67	40.00	53.33
Loss by evaporation in percentages.						
September 21	94.75	39.51	26.34	14.78	9.81	8.96
September 22	5.68	17.02	10.22	10.09	7.75	7.48
September 23	......	18.85	14.87	13.39	10.33	9.05
September 24	......	12.16	14.56	11.82	8.99	8.09
September 25	......	7.29	6.20	7.30	5.27	7.05
September 26	......	3.04	6.82	8.17	6.92	6.70
September 27	......	1.82	5.89	3.48	3.51	3.48
September 28	......	......	5.58	3.65	2.58	3.04
September 29	......	......	4.34	2.96	1.86	2.61
September 30	......	......	2.48	1.74	1.76	2.00
October 5	......	......	2.79	5.55	6.31	7.22
October 10	......	......	......	2.09	2.89	2.95
Total in 20 days	100.43	99.69	100.09	85.02	67.96	68.63

These experiments give us some idea as to what percentage of the rainfall remains in the soil for the use of the plant in the case of large and small rains, but do not quite answer the question how one and the same quantity of rain is utilized in moistening the earth when it is distributed through a larger or smaller number of rainy days.

On this latter question Wollny has made the following experiment: A quantity of water corresponding to a rainfall of 60 millimeters was communicated to an experimental tub, No. 1, all at once, while in tub No. 2, 30 millimeters were given the first time and the remaining 30 after three days; in the third tub 20 millimeters were given at first and 20 millimeters every other day thereafter, and, finally, in the fourth tub, 10 millimeters were given every day, so that in six days all had received the same quantity of water. These experiments were repeated for different kinds of soil and the results show that in all cases the quantity of water lost by evaporation is larger the more frequently the water was communicated or the greater the number of rainy days. A fine illustration of the truth of this principle as applied to practice is narrated by Haberlandt, who found that in 1874 the farmers at Postelberg got much better crops than those at Lobositz, which could only be attributed to the fact that during that year Postelberg had received 246 millimeters of rainfall in forty days, or an average of 6, whereas Lobositz had received 309 millimeters in seventy-seven days, an average of 4, so that the usefulness of the greater quantity of rain in Lobositz did not equal that of the smaller quantity at Postelberg.

Wollny shows that since the period of the heaviest rainfall occurs throughout central Europe at the time of the largest evaporation from the soil we must conclude that for the naked earth the wetting of the soil during the warmer season of the year is controlled much more largely by the rainfall than by the evaporation depending on the temperature. His observations with the lysimeter show that the precipitation is principally concerned in the moistening of the naked soil during the warmer season, while the influence of the temperature and the resulting evaporation nearly disappears and is only observable in periods that are deficient in rain. In most cases the vegetation is injured when the atmospheric precipitation during the coldest season of the year is insufficient. The precipitation at this time of the year is therefore quite as important for the success of the harvest as that which falls during the period of vegetation. (Wollny's Forschungen, Vol. XIV, pp. 138-161.)

A. Seignette has shown that the law of levels propounded by Royer is confirmed. This law states that for given plants and for other uniform conditions the reserve nutriment in the earth is always found at a constant distance below the surface; thus the bulbs of

a plant under given conditions are found at a given level, and if we change these conditions as to moisture, temperature, etc., we shall change the distance from the surface down to this level. (Wollny's Forschungen, Vol. XIV, p. 132.)

TRANSPIRATION.

The quantity of water transpired by trees and plants depends upon the amount of water at their disposal, as well as on the temperature and dryness of the air, the velocity of the wind, the intensity of sunlight, the stage of development of the plant, the amount of its foliage, and the nature of its leaf. The following are some of the results of measurements at European experiment stations. (See Fernow, Report, 1889, p. 314.)

F. B. Hoehner found that the transpiration per day per 100 grams of dry weight of leaves is for conifers 4.778 to 4.990 grams, but for deciduous trees about ten times as much, 44.472 to 49.553. During the whole period of vegetation a unit weight of dry leaves corresponded to a total weight of evaporated water, as shown by the following table, for three different years.

Transpiration of water corresponding to growth of unit weight of dry leaves.

Plant.	1878.	1879.	1880.	Plant.	1878.	1879.	1880.
Birch and linden	650	1,000	90	Oaks	250	400	59
Ash	550	700	101	Spruce and Scotch pine.	60	150	13
Beech	475	600	91	Fir	35	100	9
Maple	425	550	70	Black pine	85	75	7

The variability of transpiration is shown by the action of a birch in the open air, which transpired on a hot summer day from 700 to 900 pounds, while on other days it probably transpired not more than 18 to 20 pounds. A beech about 60 years old had 35,000 leaves, whose total dry weight was 9.86 pounds; hence its transpiration, at the rate of 400 pounds of water per pound of leaves, would be 22 pounds daily. An acre containing 500 trees would, during the total period of vegetation, transpire nearly 2,000,000 pounds of water, or about 50 pounds to the square foot.

A younger beech, thirty-five years old, with 3,000 leaves and a dry weight of 0.79 pounds, would, under the same conditions, transpire 470 pounds per pound or 2½ pounds per day from June to November. An acre containing 1,600 such trees would transpire about 600,000 pounds per acre or 15 pounds to the square foot from June to November.

Of the entire mass of wood and foliage on an acre of forest from 56 to 60 per cent of the weight is water and 44 to 40 per cent dry sub-

stance. In agricultural crops the amounts of water are still larger, sometimes reaching 95 per cent of the whole weight.

The amounts transpired by cereals, grasses, weeds, etc., are considerably larger than the preceding, as shown by the following table compiled from Wollny's results:

Plant.	Year.	Beginning of vegetation.	End of vegetation.	Water consumption per acre.	
				Pounds.	Inches.
Winter rye	1879	Apr. 20	Aug. 3	2,590,000	10
Barley	1879	....do...	....do...	2,720,000	11
Peas	1879	....do...	....do...	3,140,000	12
Red clover	1879	....do...	Oct. 1	3,070,000	12
Summer rye	1880	....do...	Aug. 14	3,000,000	12
Oats	1880	....do...	Sept. 14	3,420,000	14
Beans	1880	....do...	Sept. 10	3,140,000	12
Red clover	1880	....do...	Oct. 1	4,110,000	16

The following table is given by Risler (1873) in his "Note on the diminution of the volume of water courses," and shows the mean daily consumption of water by plants, expressed in millimeters of depth of water over the area of the field:

Plant.	Daily consumption of water.	Plant.	Daily consumption of water.
	mm.		*mm.*
Lucerne grass	3.4....7.0	Clover	2.9
Prairie grass	3.1....7.3	Rye	2.3
Oats	2.9....4.9	Vine	0.9....1.3
Beans	3.0+	Potatoes	0.7....1.4
Maize	2.8....4.0	Pine forest	0.5....1.1
Wheat	2.7....2.8	Oak forest	0.5....0.8

These numbers have been deduced from the results of many years of experiments in the laboratory and from observations made in a drained field under conditions favorable to this kind of research. The crops have necessarily varied from one year to another, but unfortunately I am not acquainted with these details.

The transpiration of the plant is only a means to an end. (See Marié-Davy, 1875, p. 209.) Its object is the introduction into the vegetable organism of the mineral elements necessary for the development of its tissues and that of the other principles united there. The experiments of Woodward and those of Lawes have already shown us that the same quantity of water is not always necessary in order to furnish the same amount of mineral substance and to produce in the plant all the elaboration and movements of organic products which should be produced there.

It appears evident that in soils more or less fertile and which con-

tain in unequal quantities soluble and nourishing principles the water absorbed by the roots may be more or less charged with these elements. We can understand, then, that the quantity of water necessary to enable a plant to furnish a given result is not the same for all soils, and that the richest soils may produce a greater result with a proportionably smaller consumption of water. By increasing the richness of the soil in soluble substances that can be assimilated, we should succeed in economically reducing the quantity of water consumed by the crops. In any case we might at the same time ask ourselves if all the water absorbed by the roots and introduced into the plant is utilized by it and at what limit the richness of the water should be arrested so as to be really profitable to the plant. In this connection Marié-Davy cites the following fact, mentioned by Perret in the Journal of Practical Agriculture for 1873:

In Perret's experiments a meadow having been covered with a sufficient quantity of nitrate of soda for a nitrogenous manuring of four years, the grass was magnificent in the spring. This grass was given green to the horses, who before long began to show strong diuretic symptoms accompanied by raging thirst. These animals seemed to be completely under the influence of the administration of a strong dose of nitrate. The following year there was a complete cessation of the beneficial effects of the nitrate on the meadow, which showed conclusively that the plants of the first year contained nitrate in a natural state and not decomposed by the assimilation.

When nutritive substances are given to plants in abundance they can absorb a quantity of these elements besides what is necessary for their nourishment. This is particularly true when in the series of minerals which compose a normal nourishment, one of these substances is in excess of the others. Besides, if we compare the chemical composition of a crop cut green with that of a similar crop after arriving at maturity, we find that in the latter there is a diminution in weight of several of the substances present in the former. It would, therefore, have been interesting to know if the trouble mentioned by Perret was continued with the same intensity in the dry hay.

RELATION OF PLANTS TO MOISTURE OF SOIL.

E. Wollny (1887, Vol. X, p. 320) gives some results as to the influence of plants and shade on the moisture of the soil, being a modification of a memoir published by him in 1877. His conclusions are as follows:

(1) The water contained in the soil under a covering of living plants is, during the growing season, always less than in a similar layer of fallow, naked soil.

(2) The cause of the drying up of the soil by the plants is to be found in the very considerable transpiration of aqueous vapor by their leaves.

(3) The plants deprive the soil of water in proportion as they stand closer together and have developed their tops more luxuriantly.

(4) The influence of the vegetation on the moisture of the soil extends to the deeper layers of soil.

(5) The moisture of the soil under a layer of inert objects, such as dead plants, manure, straw, pieces of wood, windfalls, etc., is always greater than that of the uncovered soil.

(6) The retention of the moisture in the soil under a cover of dead matter is a consequence of the protection afforded by the latter against the influences that favor evaporation.

(7) The quantity of moisture in the soil is, within certain limits and to a depth of about 5 centimeters, or 2 inches, greater in proportion as the covering of dead matter is thicker.

(8) The soil shaded by living plants is, under otherwise similar conditions, driest during the growing period, but that covered by dead objects is the moistest, while that which is not cultivated, not covered with plants and naked, is midway between the two previous in reference to its relations to moisture.

Wollny has also studied the influence of plants and shade upon the drainage of water from the soil. His conclusions are:

(1) A notably smaller quantity of water drains through the soil supporting living plants from the same quantity of rainfall than through a naked soil during the growing season.

(2) The quantity of drainage in cultivated fields is less in proportion as the plants stand more closely together and in proportion as they have developed themselves more luxuriantly.

(3) The quantity of drain water from a soil covered by inert objects is increased in comparison with that from fallow land in proportion as the covering layer is thicker, up to a certain limit, up to about 5 centimeters, beyond which a further increase in the thickness of the covering steadily diminishes the quantity of drainage water.

(4) For the same quantity of rain and under otherwise similar circumstances, the soil covered with dead leaves and similar objects furnishes the greatest quantity of drainage water up to a covering of about 5 centimeters thickness; the naked, fallow land furnishes the next smaller quantity of water; the soil covered with living plants furnishes the least quantity of drain water.

RELATION OF WATER TO CROPS.

E. Wollny has studied the relation of the irrigation and rainfall to the development and productive power of plants in cultivated fields, and the following summary is essentially as given by him in Volume X of his Forschungen for 1888, page 153.

An early investigation of this subject was made by Ilionkoff, who filled five large tubs with soil and sowed buckwheat in each on the 15th of May; each tub was then watered regularly with a definite quantity of water, the total quantity used being given in the second column of the table following. The relative quantities of buckwheat harvested at the end of the season are given in the third column and the straw is given in the fourth column. The weight of the buckwheat originally sown in each tub was the same, viz, 0.154 gram.

Tub No.—	Total water applied.	Weight of green harvest.			Weight of dry harvest.		Number of kernels harvested.	Ratio of straw and kernels to the seed.
		Grain.	Straw.	Sum total.	Grain.	Straw.		
	Liters.		*Grams.*	*Grams.*	*Grams.*	*Grams.*		
1	25.00	1.89	26.10	27.99	1.68	4.52	111	45
2	12.50	6.15	58.85	65.00	5.47	8.47	283	100
3	6.25	1.95	23.03	24.98	1.73	4.55	93	46
4	3.12	.58	9.42	10.00	.52	1.41	37	14
5	1.56	.10	2.20	2.30	.09	.30	12	3

These figures show plainly that the plants in tub No. 2 were most favorably situated. Probably No. 1 had too much water and Nos. 3, 4, and 5 too little.

Haberlandt, in 1866, experimented on the quantity of water needed in the growth of plants in three plats of 14.41 square meters each; of these No. 1 received no artificial watering; No. 2 was watered once a week, except in great droughts twice a week; No. 3 received a double quantity once a week. These quantities corresponded to a rainfall of 6.46 millimeters for No. 2 and 13.92 millimeters for No. 3. The total quantities for the season were 96.96 and 193.92 millimeters. The natural rainfall was as follows:

Month, 1886.	Rainy days.	Rainfall.
		mm.
March	17	40.98
April	15	35.38
May	11	52.20
June	13	46.03
July	17	34.40
Total	73	208.99

The number of rainy days was large, but the rainfall was small, and the plants in bed No. 1 suffered for want of water. The relative harvests for the different beds and crops were as follows:

Plant and bed.	Harvest (relative numbers).		Plant and bed.	Harvest (relative numbers).	
	Grain.	Straw.		Grain.	Straw.
Wheat:			Barley:		
1	100	100	1	100	100
2	132	129	2	109	105
3	172	164	3	216	123
Rye:			Oats:		
1	100	100	1	100	100
2	136	124	2	133	116
3	161	219	3	182	126

Beds Nos. 1 and 2 showed about the same rate of growth. No. 3 showed a retardation. The barley and the rye were harvested from this bed four days later than from the other two. The quantity of harvest increased with the quantity of water, and the harvest of grain, except in the case of the wheat, was more increased by watering than was the harvest of straw; the quality of the grain showed only slight differences.

Hellriegel experimented (1867–1883) on the influence of water upon the crops. He filled a number of vessels with quartz sand and maintained the earth at a different state of dryness. The experiments were repeated for several years on wheat, rye, and oats, the general results being that when the ground contained from 60 to 80 per cent of its full capacity of water the harvest was larger than when the ground was drier and about in the following proportions:

Tub.	Moisture.	Wheat crop.		Rye crop.		Oat crop.	
		Straw.	Grain.	Straw.	Grain.	Straw.	Grain.
	Per ct.						
1	80-60	22	11.0	16	10	16	12
2	60-40	21	10.0	15	10	14	11
3	40-20	15	8.0	12	8	12	8
4	20-10	7	2.8	12	4	4	2

Hellriegel also varied the experiment by giving the tubs daily, each evening, as much water as they had lost during the day, thus

maintaining a very constant state of moisture in each. with the following results:

Tub.	Constant moisture.	Harvest.		Tub.	Constant moisture.	Harvest.	
		Straw.	Grain.			Straw.	Grain.
	P. ct.				*P. ct.*		
1	80	11.0	8.8	5	20	6.9	7.7
2	60	12.8	9.9	6	10	3.0	3.8
3	40	11.2	10.5	7	5	0.1	....
4	30	8.8	8.8				

The general result, therefore, was that the largest harvest is given by soil containing 40 per cent of its maximum capacity for water. The general appearance of the plants showed that those having too little water had a less intensive life and were suffering from lack of nourishment rather than from the want of pure water itself.

Fittbogen (1873) conducted a series of experiments on twenty tubs in groups of four. The relative weights of his harvests of oats were as follows:

Tub.	Moisture.	Harvest.		Tub.	Moisture.	Harvest.	
		Straw.	Grain.			Straw.	Grain.
	P. ct.				*P. ct.*		
1	80-60	7.7	6.0	4	30-20	3.7	4.0
2	60-40	6.9	5.3	5	20-10	0.9	0.6
3	40-30	7.7	6.1				

These figures show that for moistures varying between 30 and 80 per cent there was very little difference in the harvest, while for drier soils the harvest was decidedly diminished; but it is notable that for the driest soil (No. 5) the grain ripened earliest of all.

Haberlandt, in 1875, reports the results of experiments on three tubs sown with summer wheat. The quantity of water allowed to tub No. 1 was just sufficient to keep the wheat alive; the other quantities, with the harvest, are given in the following table:

Tub.	Quantity water.	Number waterings.	Equivalent rainfall.	Harvest.	
				Grain.	Straw.
	cc.		*mm.*		
1	6,200	31	24.4	21.8	6.6
2	14,400	36	56.6	29.4	16.4
3	24,800	31	97.5	41.6	31.6

Whence it would seem that the limit of useful water had not yet been reached.

Birner (1881) experimented on the amount of water needed by potatoes. Four series of experiments were made, each including five tubs having different amounts of water, as shown in the following table, which gives the average of the four series:

Tub.	Moisture.	Harvest weight of tubers.	
		Per plant.	Average per tuber.
	P. ct.	*Grams.*	*Grams.*
1	80-60	809	42
2	60-40	628	46
3	40-30	413	42
4	30-20	313	34
5	20-10	214	23

These figures show a steady increase in the amount of harvest with increasing moisture.

The student will notice that in these experiments where the plants are kept in tubs under protection from natural rains the watering and growth go on under continued sunshine. The experiments therefore correspond with the case of irrigation in a dry, sunny climate, and it is not to be understood that the same amount of water deposited naturally by clouds, with attendant long-continued obstruction of sunlight and heat by the clouds, would have produced the same large crops.

R. Heinrich (1876) experimented at Mecklenburg on the influence of water on grasses and clover. Ten sets of tubs filled with sterile sand were sown with grasses and clover and watered daily, with results as shown in the following table:

Tub.	Weight of daily water.	Equivalent daily rainfall.	Harvest weight of fresh-cut grass.	Tub.	Weight of daily water.	Equivalent daily rainfall.	Harvest weight of fresh-cut grass.
	Grams.	*mm.*	*Grams.*		*Grams.*	*mm.*	*Grams.*
1	100	1	35	6	600	6	138
2	200	2	44	7	700	7	148
3	300	3	57	8	800	8	161
4	400	4	84	9	900	9	156
5	500	5	110	10	1,000	10	170

This shows that the harvest increased steadily up to 8 millimeters of rainfall daily, but for 9 or 10 millimeters per day the increase in harvest was so slight that we may consider 9 millimeters, with an average harvest of 162 grams, as the best that could be obtained under the temperature and sunshine prevailing that year at Mecklenburg. Doubtless a different quantity of water would be required in order to obtain the maximum harvest in other climates.

E. Wollny (1882–83) made seven series of experiments, in each of which five or six tubs received daily different quantities of water, except only that in the driest tubs extra water was given for the first few days in order to insure the sprouting of the seeds, and except, further, that in the experiments of 1882 the water was given every second or third day instead of daily, whereby was brought about the rather large variations in the moisture of the earth. The tubs were shielded from natural rain, were of the same size, and had the same weight of earth and aliment. Nothing is said as to whether special manure or fertilizer was used, but only that all were treated perfectly alike except as to water; the effect of manuring was shown only in the case of Nos. 6 and 7 in that No. 6 was treated like the previous ones, while No. 7 received a supply of mixed Peruvian guano, superphosphate, and sulphate of lime, gypsum, or plaster equivalent to 526 kilograms per hectare. Exact measurements were made upon six plants in each tub in order to judge of the relative harvests. An abstract of Wollny's measures is given in the following tables:

EXPERIMENT OF 1882.

Tub.	Moisture.	Grain harvest dried in air.			Mixed grain.
		Summer rye.	Beans.	Summer rape seed.	
1	100–80	4.3	9.2	2.4	11.0
2	80–60	5.7	11.1	4.4	13.9
3	60–40	5.1	11.6	4.9	12.7
4	40–20	3.9	3.3	2.0	9.4
5	20–10	0.4	0.5	0.25	1.8

EXPERIMENT OF 1883.

Tub.	Moisture.	Grain harvest dried.		
		Horse bean.[a]	Summer rape seed.	
			Not warmed.	Warmed.
1	100	7.4	0.2	0.3
2	80	21.9	3.3	3.9
3	60	14.0	4.2	4.3
4	40	10.6	4.6	6.9
5	20	3.5	2.5	2.7
6	10	1.3	0.8	1.4

[a] A variety of English or Windsor beans (*Faba vulgaris*) raised in Europe for feeding horses.

He concludes that, in general, the quantity of harvest is influenced to an extraordinary degree by the quantity of available water and much more than by any other factor of vegetation. In general the

harvest increases with increasing water supply up to a definite limit, beyond which the harvest diminishes steadily for any further increase in the water supply, until when the earth is completely saturated with water the harvest in some cases becomes almost nil. The most advantageous percentage of moisture in the soil varies for the different plants, depending on their own method of using the water, on the evaporation from their leaves, and on the number of plants to the unit of area of the field, namely, their closeness to each other.

In reference to the needs of practical agriculture it would be improper to consider in such experiments as these only the water that has been used, since the number of plants to the unit area is of equal if not greater importance. It would therefore be improper to reason from these experiments up to the needs of another field or tub having a greater or less plant density. Again, as also shown by Wollny, more water is used in proportion as more nutriment is available in the ground, because the development of the organs of transpiration or the leaves is thereby increased. Therefore, in general, the quantity of water required to attain the maximum crop will increase with the richness of the soil and the closeness of the plants as well as the dryness and velocity of the wind. For different crops, moreover, the absolute quantity of water will depend upon the duration of the whole process of vegetation, from germination to harvest. (See Wollny, 1881, IV, p. 109.)

The character of the plant affects the quantity of necessary water, not only by the duration of the process, but by the relative quantity of auxiliary organs that the plant develops in order to produce the ripened seed, which we call the harvest. The ratio of the grain to the straw and chaff when the maximum crop of grain is produced in each of Wollny's seven cases is shown in the following table:

Maximum harvest dried in air.

	Grain.	Straw and chaff.	Ratio.
			P. ct.
I. Summer rye	5.7	12.0	48
II. Peas	11.6	15.4	75
III. Summer rape seed	4.9	7.6	65
IV. Horse bean	21.9	31.6	69
V. Colza bean without manure	4.6	15.4	30
VI. Colza bean with guano	6.9	17.1	40

These percentages show the success with which the plant labors to perpetuate its species with the least possible waste of molecular energy on extraneous matters.

Hellriegel's experiments gave 80 to 60 and sometimes 40 per cent, Fittbogen's gave 40 to 30 per cent, Wollny's gave 80 to 60 per cent of moisture for the maximum harvest. These differences undoubtedly arose, at least in part, from differences in richness of the soil, the closeness of the plants, and differences in the sunshine and wind. These results are therefore in general only relative, and justify us in saying that the best crops are obtainable when the earth contains from 40 to 80 per cent of its maximum capacity for water and that the percentage is higher in proportion as the soil is richer; as the plants are closer; as the leaves of the plants are broader; as the sunshine, the dryness of the air, and the velocity of the wind are greater; and as the barometric pressure is less, since all these increase the useful evaporation from the leaves and the wasteful evaporation from the soil.

The growth of the auxiliary organs was shown by Fittbogen, who gives the weight of the organic matter as determined by burning the well-washed roots, and is also shown by Haberlandt by the weights of the roots and stubble. Their measures are given in the following tables:

FITTBOGEN'S EXPERIMENTS.

Moisture in the soil.	Organic matter lost by burning.
Per cent.	*mg.*
80–60	470
60–40	429
40–30	440
30–20	359
20–10	109

HABERLANDT'S EXPERIMENTS.

Water.	Weight of roots and stubble.
cc.	*Gram.*
24,800	5.35
14,400	3.2
6,200	2.9

Again, the variation in the stock independent of the grain is shown by the measurements of the dimensions of the heads and stocks as given in the following tables:

OATS (FITTBOGEN'S EXPERIMENTS).

Moisture.	Number of shoots.	Length of heads.	Diameter of heads.
Per cent.		*mm.*	*mm.*
80-60	8	555	3.9
60-40	3	442	4.1
40-30	4	450	3.6
30-20	2	250	3.3
20-10	4	136	1.4

SUMMER WHEAT (HABERLANDT'S EXPERIMENTS).

Water.	Number of stalks.		Height of stalks bearing heads.	
	Bearing heads.	Not bearing heads.	Shortest.	Longest.
			cm.	*cm.*
24,800	18	12	70	95
14,400	12	18	30	65
6,200	5	16	20	35

Similar experiments by Sorauer (1873) give results analogous to the preceding. He measured the greatest length and width of the leaves, at several stages of their growth, of barley plants in tubs of different moistures, with the average results for all stages of growth, showing that the leaves were longer and broader the more water was furnished, while the available nutrition remained the same.

BARLEY (SORAUER'S EXPERIMENTS).

Moisture.	Length of leaf.	Width of leaf.
Per cent.	*mm.*	*mm.*
60	182.2	9.4
40	166.3	9.1
20	138.7	6.8
10	93.7	5.6

These and similar observations show that the assimilating organism of the plant (viz, its leaves), as also its organism for absorbing nutrition (viz, its roots), both alike increase with the increase in available moisture near the roots in the earth, at least within the limits existing in these experiments, and to the same extent is the development of the plant favorable to the increase of its productivity.

Under such circumstances it is not surprising that the development of the crop of grain keeps pace with the increase of the available water, at least up to the point where the quantity of water is sufficient to give a maximum crop.

The supply of water has an influence not merely on the quantity of the crop, but also on the rapidity of the development of the plant. Wollny (1881) shows that in general the grain ripens sooner as the quantity of water diminishes. This is well seen in the following series of experiments (Table 62) on the time of ripening of grain in fields that are sown more or less thickly. The thickly sown fields correspond, of course, to a less quantity of water available for each plant.

WINTER RYE (WOLLNY, 1875–76).

Number of plants to the square meter.	Number of square centimeters to each plant.	Date of ripening (1876).
625	16	July 18
400	25	July 21
229	44	July 28
100	100	July 30
25	400	Aug. 8

PEAS (WOLLNY, 1877).

Number of plants to the square meter.	Number of square centimeters to each plant.	Date of ripening (1877).
357	28	Aug. 15
157	64	Aug. 17
89	113	Aug. 19
85	117	Aug. 26
40	254	Aug. 28
29	346	Sept. 5

POTATOES.

Similar experiments were made by Wollny on the *Ramersdorfer* variety of potatoes. A plat containing 1 plant to 4,435 square centimeters ripened by the end of September (1875), but a plat containing 1 plant to 812 square centimeters ripened the 1st of August, and other plats containing 1 plant to 2,500, 1,600, 1,109 square centimeters, respectively, ripened at dates proportional to the area occupied by each plant. As each plat received the same amount of sunshine and of water, the dates of ripening must have been hastened in proportion as the number of plants in each plat were increased.

MAIZE.

Similar experiments on maize showed a similar acceleration of the date of ripening, as given in the following table, which also shows in the last column what proportion of the maize was unripe in the sparsely planted plats when that which was closely planted was already fully ripe.

MAIZE (WOLLNY, 1875).

Number of plants to the square meter.	Number of square centimeters to each plant.	Order of ripening.	Percentage of unripe ears.
25	400	1	3.7
16	625	2	0.0
9	1,109	3	26.7
6	1,600	4	34.8
4	2,500	5	56.2

FLAX.

A striking illustration of the effect of scant water supply is given in the case of four plats of flax, which were sown at the rate of 50, 100, 150, and 200 grams of seed per 4 square meters of ground. During the drought of 1875 the plants sown most closely all died early in July, whereas those sown most sparsely withstood the drought very well; of the plants sown with intermediate densities the number that died was proportional to the density. In general, if all other conditions are the same, plants ripen sooner and have a shorter duration of vegetation in proportion as the soil is drier, or in proportion as there are more plants to the unit area.

Evidently the plants whose roots extend the farthest in search of water will outlast the species or varieties whose roots are of smaller dimensions.

RAINFALL AND SUGAR BEETS.

Briem (1887) has investigated the effect of rainfall on the harvest of sugar beets. His observations were made at the experiment station "Gröbers." A long drought during August and September was followed by a rainy period of many weeks. During the latter the beets increased in weight on an average for each beet from 388 to 450 grams; the presence of sugar was shown by the ordinary polarization test, both before and during the rainy period. The following table gives the results of the analyses, each figure being the average of 16 readings on samples taken from 100 beets. These samples show that immediately after the first rainfall, on September 21, the percentage of sugar per beet diminished somewhat, but that toward the

end of the rainy period, when the rainfalls became less frequent, the percentage rose to nearly its former value. On the other hand there was a regular diminution of the other elements that were not sugar, and consequently an improvement in the percentage of purity. Therefore a permanent injurious influence of the heavy rainfall on the quality of the beet was not proven.

Date of measures.	Number rainy days.	Percentage of—		Quotient.	Percentage of not sugar in 100 of sugar.
		Sugar.	Not sugar.		
September 20 (before rain)	0	13.13	3.27	80.0	24.9
September 27 (after rain)	6	12.35	3.15	79.6	25.4
October 9 (after rain)	9	12.56	2.84	81.5	22.5
October 20 (after rain)	3	13.04	2.81	82.3	21.4

Grassmann (1887) also confirms the results of Girard to the effect that the sugar once formed in the beet remains there, no matter what the further growth may be. There the diminution of the percentage of sugar after a rainfall is only relative in that the sugar is dissolved in more sap, and this is distributed throughout a greater mass of beet; the sugar, and with it the percentage of purity, sinks only very little after the first rainy day, but on the second sinks more considerably and then slowly rises from the third to the fifth day. (See Wollny, X, p. 300.)

REMARKS.

Now that the previous studies have shown the importance in agriculture of the quantity of available water the question still remains whether the results of these experiments are directly applicable to determining the influence of rainfall on vegetation under the natural climatic conditions. We could in advance answer this question in the negative, inasmuch as the precipitation is never so uniform as the water artificially supplied in these experiments, as also because the utilization of the natural rainfall by the earth varies with the physical properties of the latter; but by a closer consideration one is led to the conclusion that in spite of the departure from natural conditions still the results of these experiments do allow us to draw many conclusions as to the influence of rainfall on the growth of cultivated useful plants, especially when we leave out of consideration the effect of the water at different epochs of vegetation and the peculiarities of the capacity of the soil for water, and at first study only the average character of the climate as depending on the amount of precipitation and consider the weather during the growing season.

In this case it would scarcely be denied that a relatively dry or moist climate or any similar modification of the weather should exert an influence on the vegetation similar to that exerted by the soils of different moistures in the above-described experiments. We must the more readily agree to this conclusion since, independently of the fact that water belongs to the most important, indispensable factor of vegetation, it is also true that the observations on the growth of plants made in climates having different degrees of moisture agree closely with the views above explained. It is already well known in agriculture that in a dry climate the harvests are only scanty and to an extraordinary degree dependent on the rainfall, and, furthermore, it is well known how favorably the general condition of the plants is affected by a moderately moist climate, and how, on the other hand, the crops of cultivated lands are diminished by extremely large quantities of rain, when in consequence of a large capacity of the soil for water, a large quantity of water accumulates in it either temporarily or for long periods of time. Furthermore, it is well known that the stalk of the plants and the formation of straw are greater in proportion as the climate is moister; that the various kinds of cereals in dry regions produce a glassy, glutinous grain, but in moist lands a mealy seed, poor in nitrogenous compounds. All these phenomena, observed on a large scale in the life of the useful plants, make themselves felt also in a similar way in the experiments above quoted, and therefore the results of the latter can with perfect justice be quoted in deciding upon the questions lying at the base of our work. But these present conclusions hold good only for the total rainfall during the growing season, and it will be further necessary to fix in a similar way, by experiments, the influence of precipitation during the individual stages of growth of the plants, as also the relation of the soil to the water, so as to determine the influence of the ordinary natural climatic conditions.

Chapter VII.

MISCELLANEOUS RELATIONS.

RAPID THAWS.

The following extracts from a report for 1889 of the department of the interior of the Canadian government shows the influence of the change from warm to cold weather not only on forest trees but on other plants:

Considerable attention has been paid to this subject during the past year, and there has been urged on the department of agriculture the desirability of the establishment at some point in the southwestern portion of the Northwest Territories of a farm or garden for conducting experiments on this line. Failure in tree culture so far as tried seems to be owing not to the severity of the winters, nor to the droughts of the summers, but to the winds. Those in the winter known as "chinooks," which cause the sap to rise and the buds to swell, being followed by a lowering of the temperature (in some cases very rapid), prove destructive; and during the summer there are often high, dry, hot winds which blow continuously for several hours and which seem to dry up the young trees. By planting in close clumps the native trees which will grow (cottonwoods and others), and among them those ornamental trees which are so much to be desired, these difficulties will probably be overcome, and in time it will be found what ones are best suited to the district.

The great difficulty which at present impedes the cultivation of large plantations of forest trees in Manitoba and the northwest is climatic. In early spring, delightfully soft, balmy days, something like the maple-sugar weather in Ontario and Quebec, awaken the young trees to life and cause the sap to run; but then suddenly a terrific blizzard from the north and northwest comes down and freezes up the sap and destroys the trees. Professor Saunders is now engaged in experiments with a view to overcoming this climatic obstacle. I have thought that by planting the young trees very closely together, or by sheltering them during their earlier seasons, as is done in the case of the seedlings at the model farm at Ottawa, this trouble might be gradually lessened; or, willows or cottonwood might be planted with the young trees as a shelter-belt protection for them against these early spring frosts and sudden and extreme changes of temperature. As yet, of course, we have no practical experience in the northwest on the subject, and can only base any action we may take upon knowledge obtained from what has been

done in other countries with the same characteristics both of soil and climate. (See American Meteorological Journal, 1891, Vol. VII, p. 41.)

WIND.

The effect of the wind on vegetation is quite various. Among other influences, we note the following:

(*a*) It is considered that the mechanical action of the motion of the stems and trunks and stalks is to strengthen them and to stimulate the growth of the roots.

(*b*) The winds distribute the pollen and the seed and thus assist, or even entirely control, the preservation of the plant and its geographical distribution.

(*c*) The wind renews the air, so that a superabundance of the necessary gases is then assured.

(*d*) During cool, clear nights a wind, by renewing the supply of heat, prevents the formation of frosts by radiation.

(*e*) On dry, cold, frosty nights the wind, by its dryness, evaporates any frost that may be formed upon the plant, but does not prevent the freezing of the plant as a whole.

(*f*) By bringing moisture, fog, and clouds from the lakes and ocean up over the fields and forests the wind prevents frosts and favors the growth of delicate plants on the leeward side of large masses of water.

(*g*) Gasparin states that when a cold, dry north wind suddenly blows over plants in active growth they become stunted, and it is said that the plants have taken cold. A similar phenomenon occurs in the valleys of California.

Gasparin's description is as follows (Cours d'Agriculture, 2d ed., 1852, p. 202):

> In the valley of the Rhone the north wind produces a lowering of the normal temperature of about 7°; all the vegetation is more or less involved if after several days of calm, clear weather, during which the heat has increased, such lowering of temperature is experienced. Even if there has been no frost and the plants have preserved their vitality unimpaired, it produces a singular effect on them; their growth stops and they remain stunted. Our agriculturists describe this condition by saying that the plants have "taken cold." The leaf buds which put out later resume their growth, but the leaves and branches experiencing this cessation of growth never entirely recover from it. This accident is especially injurious to natural and artificial meadows and to the leaves of the mulberry tree. As regards the meadows, the best thing to do is to hasten the mowing of the grass, in order to gain time for the succeeding crops to prosper, and for the mulberry trees it is advisable to await the development of new buds.

The more rapid these dry winds are the more they hasten the drying up of the soil. After they have prevailed for several days the earth

becomes hard, and this condition prolonged until spring contributes much to injure the growth of the plants. The wheat remains low and does not head; the meadows yield but little grass, if a spell of warm weather does not soon follow so that they may be irrigated, for if the wind is dry and cold at the same time watering will do them little good.

(*h*) Damp warm winds are generally favorable to plants and particularly so to various kinds of fodder. Nevertheless, we observe that under their action the fertilizing proceeds badly, growth is imperfect, and the maturing is retarded.

(*i*) Warm dry winds produce very rapid evaporation, and their effect is still more marked if, like the simoon of Arabia, they carry with them sand heated by the powerful southern sun.

(*j*) Hot dry winds occur, notably along the whole eastern slope of the Rocky Mountain Divide, which by their rapid evaporation use up all the moisture in the plant and in the soil, causing the plant to entirely wilt away.

THE ORGANIC DUST OF THE ATMOSPHERE.

IN GENERAL.

The dust contained in the atmosphere, in so far as it consists of organic débris, has a slight influence on agriculture, but in so far as it consists of living germs seeking places to rest and grow it is a matter of vital importance. Undoubtedly most of the plant diseases are spread in all directions by the winds that carry the spores of fungi even more widely than they do the seeds of the weeds. But the examination of this dust, either by the microscope or by cultivation in various appropriate moist media, as also the study of the injuries or the good done by the microbes, bacteria, bacilli, micrococci, fungi, and other organisms, belongs to vegetable pathology rather than to the relations between climates and crops and is a subject so large that we must refrain from even attempting to quote the titles of recent treatises on the subject by Pasteur, Miquel, Van Tieghem, Koch, Kohn, and many other prominent authors in Europe and America. Systematic daily examination by the culture method of the dust deposited from the air had been established at Montsouris under Marié-Davy, and at Philadelphia under Dr. J. S. Billings, and will undoubtedly do much to explain the dependence of crop diseases upon wind, moisture, and temperature.

WIND AND FORESTS AND GERMS.

The influence of the forests on the transportation of the microorganisms by the wind has been studied by A. Serafini and J. Arata

by counting the collections of organisms that are caught and developed on appropriate glass plates prepared according to the methods of Miquel at Montsouris. Their observations show that in 39 cases out of 40 the catch of germs within the forest is less than the catch outside the forest, the average ratio being as 3 to 1, so that the forests act as a strainer upon the organisms carried by the wind. Wollny suggests that the result would be even still more decided if the wind were stronger and the forests more extensive. (Wollny, Forschungen, 1891, XIV, p. 176.)

ATMOSPHERIC ELECTRICITY.

IN GENERAL.

The relations of atmospheric electricity to vegetation and crops are too little understood to justify any attempt to present this subject. In fact, it does not seem clear that any appreciable influence is exerted by this atmospheric or geophysical element upon the development of plants. In natural conditions evaporation is undoubtedly facilitated by the dissipation of an electric charge, but we do not know that transpiration is at all affected by it, and have no reason to think that assimilation is affected by it. The passage of an electric current through the earth in proximity to the roots may affect the decomposition of the soil and setting free of nutritious substances or may affect the temperature of the soil. A few experiments have been made to show that artificial earth currents stimulate the growth of the plant, but nothing has yet been found to show that under natural conditions electric currents have any appreciable influence. Nevertheless, observations are made regularly at some stations, such as Kew, Montsouris, Potsdam, and at a few agricultural experiment stations.

An excellent series was maintained for many years by Wisliczenus at St. Louis, Mo., a summary of which is published in the transactions of the Academy of Science at St. Louis and also at page 65, Report of the Chief Signal Officer for 1871. The following table gives the monthly means for Montsouris and for St. Louis. The record for Montsouris expresses the potential in units of 1 Daniell cell, which is approximately 1 volt at a point 2 meters above the soil and 1 meter from a wall, for the calm days of the years 1880 to 1887. The record for St. Louis gives the electric intensity on a scale

of arbitrary degrees for a point at the top of a house in that city for all days in the years 1861–1870:

Month.	Electric potential, Montsouris.	Electric intensity, St. Louis, Mo.	Month.	Electric potential, Montsouris.	Electric intensity, St. Louis, Mo.
January	80	11.0	July	36	2.1
February	68	9.9	August	50	2.8
March	49	7.4	September	59	2.3
April	41	5.6	October	65	5.8
May	39	4.0	November	73	8.0
June	39	2.4	December	80	8.3

These observations agree with those throughout the world in showing that the intensity is least in the summer seasons and greatest in the winter seasons of the respective hemispheres. There is also a corresponding slight diurnal variation, in accordance with which the intensity at a given point is least at 3 p. m. local mean time.

Chapter VIII.

RELATION OF PLANTS TO ATMOSPHERIC NITROGEN.

IN GENERAL.

If the atmosphere varied largely in its chemical constituents, this would doubtless have an appreciable influence on vegetation. Laborious studies at Montsouris and elsewhere have shown that there is a measurable variation in the quantity of ozone, so called, of ammonia, and of carbonic acid gas, and Morley, at Cleveland, has shown an appreciable, but very slight, systematic variation in the proportions of nitrogen and oxygen. But all these variations are so small as compared with the variations in the quantity of air brought to the plants by the wind, that their influence on vegetation, if any, can not be separated from that of the wind, and is probably entirely inappreciable as compared with other influences.

On the other hand, the general fact that plants must have nitrogen in order to produce albuminous and other nitrogenous compounds has long been apparent. The question how to furnish this nitrogen to the plants in such a chemical form that it can be readily assimilated by the cells has undoubtedly been, consciously or unconsciously, the problem of the agriculturist for many ages. Without nitrogen, which is usually supposed to be furnished by fertilizers, manures, rich soils, or the alluvial deposits of the rivers, no nutritious seeds are formed, and the more molecules of nitrogen that we can force the plant to take up into its tissues the more and better seed we may expect to obtain in the harvest.

THE AMOUNT OF NITROGEN BROUGHT DOWN BY THE RAIN TO THE SOIL.

According to Marié-Davy, nitrogen is added to the soil by the natural meteorological process of rainfall. Nitrogen can exist in water either as a dissolved salt of ammonia or as pure ammonia, or in the state of a nitrate or a nitrite of soda or other alkali, or as compounded with carbon, hydrogen, and oxygen, as in the case of organic bodies floating in the water. The nitrogen brought down by the rain water is washed out of the atmosphere where it had existed in some one of these forms, and, although the percentage is small, yet the abso-

lute quantity has an appreciable value as a fertilizer. The methods of determining the quantities of nitrogen need not here be given, but the following results of observations in Europe give at least an approximate idea of the probable effect of rains in the United States. (See Annuaire de Montsouris, 1889, p. 254.) Similar data for our own territory have not been measured, so far as I can find.

Quantity of nitrogenous compounds in the rainfall of 1888 at Montsouris.

Month.	Total rain-fall.	Number of rainy days.	1 liter of rain contains—		1 square meter of ground receives—	
			Ammonia.	Nitric acid.	Ammonia.	Nitric acid.
	mg.		*mg.*	*mg.*	*mg.*	*mg.*
January	21.5	12	5.15	0.84	110.7	18.1
February	38.4	13	2.19	1.00	84.1	38.5
March	87.7	26	1.51	0.61	132.4	53.3
April	55.5	16	1.50	0.78	84.2	43.2
May	19.8	7	0.80	0.82	15.8	16.2
June	79.6	16	1.10	1.02	87.9	81.2
July	76.0	22	0.56	1.36	44.0	103.6
August	47.5	11	0.88	1.10	41.7	52.5
September	23.0	4	2.33	0.87	53.6	20.1
October	19.4	11	2.62	0.68	51.4	13.2
November	48.3	17	2.21	0.85	106.7	41.2
December	31.6	10	3.62	0.50	114.3	15.9
Total	548.3	165			926.8	497.0
Average	45.7	14	1.69	0.91	77.2	41.4

Quantity of nitrogenous compounds in the rainfall during successive years at Montsouris.

Seasons (warm or cold).	1 square meter receives— Ammonia.	Nitric acid.	Seasons (warm or cold).	1 square meter receives— Ammonia.	Nitric acid.
	mg.	*mg.*		*mg.*	*mg.*
1875 (Sept.)-1876 (Feb.)	574.9		1883 (Mar.)-1883 (Aug.)	431.6	106.4
1876 (Mar.)-1876 (Aug.)	499.9		1883 (Sept.)-1884 (Feb.)	481.3	228.5
1876 (Sept.)-1877 (Feb.)	387.6	210.3	1884 (Mar.)-1884 (Aug.)	544.0	91.9
1877 (Mar.)-1877 (Aug.)	542.1	135.5	1884 (Sept.)-1885 (Feb.)	518.5	152.7
1877 (Sept.)-1878 (Feb.)	423.7	93.6	1885 (Mar.)-1885 (Aug.)	499.5	152.7
1878 (Mar.)-1878 (Aug.)	725.7	50.3	1885 (Sept.)-1886 (Feb.)	569.9	137.4
1878 (Sept.)-1879 (Feb.)	462.1	169.1	1886 (Mar.)-1886 (Aug.)	589.6	222.8
1879 (Mar.)-1879 (Aug.)	325.3	285.4	1886 (Sept.)-1887 (Feb.)	376.2	158.9
1879 (Sept.)-1880 (Feb.)	230.5	336.4	1887 (Mar.)-1887 (Aug.)	728.2	219.6
1880 (Mar.)-1880 (Aug.)	310.6	299.8	1887 (Sept.)-1888 (Feb.)	693.9	180.1
1880 (Sept.)-1881 (Feb.)	503.4	264.7	1888 (Mar.)-1888 (Aug.)	406.0	350.0
1881 (Mar.)-1881 (Aug.)	348.1	181.1	Average, cold seasons	503.0	191.2
1881 (Sept.)-1882 (Feb.)	415.2	83.4	Average, warm seasons	511.7	191.9
1882 (Mar.)-1882 (Aug.)	701.5	207.4			
1882 (Sept.)-1883 (Feb.)	901.7	279.0			

It is evident that there is no appreciable difference between the warm and cold seasons. A slight addition is to be made to the above table, in order to include the quantities of nitrogen contained in the water of fogs and dew. The quantities under the column "Nitric acid" includes such nitrites as become converted into nitrates in the laboratory analysis. The great variations in the successive seasons depend upon the variations in rainfall quite as much as upon the variations in the quantity of nitrogen per liter, or the variations in the atmospheric constituents.

The variations in the quantity of nitrogen brought to the soil by the rainfall in different parts of the world is shown in the following table, as quoted by Marié-Davy from the memoir of Messrs. Lawes, Gilbert, and Warington, on the composition of the rainfall at Rothamsted. This table shows that the richness of the rain in nitrogenous compounds varies geographically quite as much as the quantity of rain does, so that in general the ground in Germany, Italy, and France receives decidedly more nitrogen per acre than does the ground in England. A further study of the subject also shows that the rain caught in cities contains vastly more nitrogen, especially ammonia, than that caught in the open country.

Quantity of nitrogen annually brought to the soil by rain.

Station.	Date.	Total nitrogen— Per hectare.	Total nitrogen— Per acre.	Station.	Date.	Total nitrogen— Per hectare.	Total nitrogen— Per acre.
		Kilos.	*Lbs.*			*Kilos.*	*Lbs.*
Kuschen	1864–65	2.08	1.86	Proskau	1864–65	23.42	20.91
Do	1865–66	2.80	2.50	Florence	1870	14.96	13.36
Insterburg	1864–65	6.15	5.49	Do	1871	11.08	9.89
Do	1865–66	7.63	6.81	Do	1872	14.01	12.51
Dahme	1865	7.46	6.66	Vallombrosa	1872	11.63	10.38
Regenwalde	1864–65	16.90	15.09	Rothamsted	1853–54	6.24	5.96
Do	1865–66	11.63	10.38	Do	1855	7.29	6.58
Do	1866–67	18.41	16.44	Do	1856	8.85	8.00
Ida-Marienhutte	1865–70	11.12	9.92	Montsouris	1876–88	14.04	12.53

The appreciable quantities of nitrogen shown in the above table must be diminished in agricultural computations in proportion as the rainfall carries it off into the rivers, since only that which remains in the soil can be supposed to have an appreciable influence on the growth of crops.

The quantity of nitrates in rain water may be expected to vary with the character of the climate and may be greatest in those regions where lightning is most frequent. Observations on this subject were made by A. Muntz and V. Marcano (Agr. Sci., Vol. III, p. 273), who showed that at Caracas, Venezuela, where thunder storms are fre-

quent and violent, there is a very large amount of nitric acid, either free or combined, in the rain water. The relative values in different climates are as follows:

Locality.	Weight of nitrogen per meter rainfall per hectare.
	Kilos.
The island of Reunion	6.93
Caracas	5.78
Rothamsted	0.83
Liebfrauenberg	0.33

NITROGEN DIRECTLY ABSORBED BY THE SOIL.

Schloesing has shown that the atmospheric ammonia has its influence upon the plant greatly multiplied by the direct absorption of this ammonia from the air into the soil. The absorption is greatest when the difference between the tension of the ammonia in the soil and that in the atmosphere is at a maximum; it is therefore greatest when the soil is moist and when nitrification converts the ammonia into nitrates as fast as it is absorbed. When the earth is dry nitrification is suspended, and the ammonia accumulates in the soil up to a certain point, beyond which the rate of absorption gradually diminishes. (Agr. Sci., Vol. IV, p. 292.)

FIXATION OF NITROGEN BY PLANTS.

Experiments as to the source whence the grains (Gramineæ) and the beans and peas (Leguminosæ) derive their nitrogen have been made both in Germany and France by independent methods. Thus Hellriegel and Wilfarth from 1883 to 1887 experimented upon samples of these plants, each of which was placed in a pot of sterilized quartz sand to which was added a nutrient solution, and the plants were watered with distilled water so as to keep the conditions favorable to growth. The results were that oats and barley behaved alike; when they are not furnished with nitrates there is no development beyond the reserve in the seed, and when they are fed with nitrates the harvest of dry matter is directly proportioned to the quantity of nitrate. For every milligram of nitrogen the increase of dry matter is 93 milligrams for barley and 96 for oats, respectively. Sterilization of the soil and of the pots on the one hand, and the addition of the microbes contained in the washings of cultivated soil on the other hand, cause no variation in the above results.

Peas behave quite differently from the preceding. Some plants languish if they have no nitrates, but others suddenly acquire new

life and yield a crop comparable with that obtained with a good supply of nitrate. The amount of nitrogen in the crop is sometimes a very large gain over that contained in the soil; this latter also occurs when the air is deprived of all ammonia, etc., and the nitrogen must be obtained from the free nitrogen of the atmosphere. But when the soil is sterilized by heat and the pots and seeds are sterilized as to their surfaces by washing with very dilute mercuric chloride, then peas behave like oats and barley; there is no gain of nitrogen from the air, the crops are proportional to the quantity of nitrate in the soil, and no tubercles are formed on the roots.

In all cases where the peas had gained nitrogen when planted in unsterilized soil, tubercles are formed on the roots, and, on the other hand, when they are planted in sterilized soil no tubercles are formed unless we add to the soil the washings of a small quantity of arable soil, in which case tubercles are generally formed. Such washings may themselves be sterilized by boiling or possibly by lower temperatures.

The authors infer that the assimilation of nitrogen from the air by peas, lupines, and other leguminous plants is not within the power of the plant as such; nor can it take place when the plant grows within a sterilized medium, but is connected with the presence of microbes and with the development of tubercles on the roots. (Agr. Sci., Vol. III, p. 215.)

The fixation of nitrogen by Leguminosæ has been studied by E. Bréal, who succeeded in inoculating Spanish beans with bacteria from tubercles on the roots of Cystisa. At first the growth was vigorous, then the plant languished, but eventually recovered, flourished, and matured. Again, lucerne, growing in a pot in sandy soil, was inoculated by laying a fragment of tuberculous root of lucerne on the soil and watering the plant with drainage water. In both these cases not only did the plants gain in nitrogen, but the soils also, so that this experiment confirms the ordinary experience as to the behavior of the Leguminosæ as soil improvers. (Agr. Sci., Vol. IV, p. 79.)

Lawes and Gilbert, in a memoir published in the Philosophical Transactions of the Royal Society of London for 1889, state their conclusions as to the sources of the nitrogen in the plant as follows:

In our earlier papers we had concluded that, excepting the small amount of combined nitrogen coming down in rain and the minor aqueous deposits from the atmosphere, the nitrogen source of crops was the stores within the soil and subsoil, whether from previous accumulations or from recent manuring. * * * With the Gramineæ it was concluded that most, if not all, of their nitrogen was taken up as nitric acid. In leguminous crops, in some cases, the whole is taken up as nitric acid, but in other cases the source seemed to be inadequate. * * * It is admitted that existing evidence is insufficient to explain the source of all the nitrogen of the Leguminosæ.

Frank had observed that the feeding roots of certain trees were covered with a fungus, the threads of which forced themselves between the epidermal cells into the root itself, which in such cases had no hairs, but similar bodies were found external to the fungus mantle, which prolonged into threads among the particles of soil. Frank concluded that the chlorophyllous tree acquires its nutriment from the soil through the agency of the fungus. Such a mode of accumulation by these green-leaved plants plainly allies them very closely to fungi themselves; but inasmuch as in the cases observed by Frank the action of the fungi was most marked in the surface layers of soil rich in humus, and since this development has not been observed on the roots of any herbaceous plants, therefore the facts hitherto recorded do not aid us in explaining how the deep and strong rooted Leguminosæ acquire nitrogen from the raw clay subsoils of Rothamsted.

In continuation of their investigations, Lawes and Gilbert have published a subsequent paper stating that in 1888 they began experiments in the same line as those of Hellriegel. Peas, red clover, vetches, blue and yellow lupins, and lucerne were sown in pots, of which there were four to each series. No. 1 contained sterilized coarse white sand; Nos. 2 and 3 contained the same sand, to which a soil extract was added; No. 4 contained garden soil or special lupin soil. Their general results were that the fixation of free nitrogen only occurred under the influence of microbes in the soils that had been seeded with soil organisms by adding soil extract to the sand in the pots. They find that the Rothamsted experiments indicate that with a soil that is rich in nitrates there are far fewer nodules on the roots of the plants than were formed in the pots of sand containing but little nitrates but seeded with soil organisms. The authors suggest (1) that somehow or other the plant is enabled under the condition of symbiotic life to fix free nitrogen of the atmosphere by its leaves, a supposition in favor of which there seems to be no evidence whatever; (2) that the parasite microbe utilizes and fixes free nitrogen and that the nitrogenous compounds formed by it are then taken up by the plant host. On this latter supposition the large gain of nitrogen, as made by the leguminous plant, when growing in a soil that is free from nitrogen but properly infected by microbes, becomes intelligible. (Agr. Sci., Vol. IV, p. 261.)

As to the relations between plants and atmospheric ammonia, almost all agree that the plant derives ammonia from the atmosphere through the medium of the soil only. Berthelot finds that vegetable soils usually have sufficient ammonia to enable them to evolve it into the atmosphere, but under certain conditions they can absorb this gas from the atmosphere. (Agr. Sci., Vol. IV, p. 295.)

Berthelot shows that vegetable soils continually absorb nitrogen from the air, and very much more than exists in the air as ammonia or nitrogenous compounds, so that it must be taken directly from the free nitrogen and this, too, although the soil contains no growing vegetables. (Agr. Sci., Vol. I, p. 120.) Apparently this absorption is the work of the microbes preparing the soil for future plant growth, and much of the irregularity in our crop reports depends not upon the climate or the fertilizer, but upon the activity of this form of life.

Berthelot (1887) shows that the fixation of gaseous nitrogen of the atmosphere by the soil takes place continually even when no vegetation is presented and that it is greater in soil exposed to rain than in soil protected from the rain, this being undoubtedly due to the fact that in the exposed soil the minute forms of life by means of which nitrogenous compounds are formed can operate more intensely because of the greater quantity of air dissolved in and carried down to them by the rain. (See Wollny, X, p. 205.)

A parallel investigation by Heraeus shows that probably the bacteria may be divided into two classes—those which oxidize and those which reduce the oxides, and that in general where an abundance of nutrition exists, as in rich soils, the reducing bacteria are in excess, and that, on the contrary, where these do not find a sufficiently favorable soil there the oxidizing bacteria have the upper hand.

Salkowsky (1887), as the result of his own experiments, considers it indubitably established that processess of oxidation in water can only be due to the vital activity of bacteria, and that this is equally true of water permeating the soil, and therefore of the oxidation processes in the soil itself.

Warington (1887), having shown that the process of nitrification goes on by means of organisms that are rather uniformly distributed at the surface, and that they are less frequent at depths of 9 and 18 inches, depending on the porosity of the soil, and that none could be found at depths of from 2 to 8 feet, has now revised these early experiments and finds a few nitrifying bacteria at depths at from 5 to 6 English feet, but that in general they are less numerous and have a feebler activity the deeper they are in the earth. Under natural conditions nitrification occurs principally in the highest layer of soil, because the conditions of this process—viz, accessibility of the air and quantity of nitrogenous compounds—are more favorable here than in the lower strata. (See Wollny, X, p. 211.)

As our views as to the relation of the nitrogen of the atmosphere to vegetation have been entirely remodeled within the past five years, the following summary by Maquenne (1891) has been selected as showing the slow progress of our knowledge up to the brilliant success of Hellriegel and Wilfarth.

Of all the characteristic functions of life nutrition is certainly the most important. It is by means of it and with the assistance of certain inanimate products which we call food that man in the first stages of his existence succeeds in increasing his size to a limit which depends upon his nature and later on succeeds in constantly repairing the loss of material which he suffers in his contact with the outside world.

Nutrition has everywhere the same object, but it may be accomplished in two entirely different ways. In the animal, considered as essentially a producer of power, nutrition is nothing more than a transformation of forces similar to that which we realize artificially in our steam engines. Nourishment must therefore contain within itself the motive power to be used by the organism which absorbs it. In other words, it should be so composed as to be capable of furnishing heat by transforming itself into more simple elements. I speak here of the organic matter which forms, indeed, the basis of nourishment in the entire animal kingdom.

With the plant, on the contrary, which is constantly absorbing energy instead of producing it, the nutriment is no longer subject to any conditions, and thanks to the living force of the solar rays, which the plant stores up in its chlorophyllian tissues, it succeeds in nourishing itself on true products of combustion—such as water, carbonic acid, and nitric acid. In other words, on substances which have reached their maximum stability and which by a concentration of force it converts to the condition of organic matter.

It is thus that the vegetable kingdom has acquired that wonderful power of combination which the methods of our laboratories so rarely attain. It is thus above all that it is able to continually reproduce the combustible matter which the animal kingdom has consumed, and that it enables a limited quantity of matter to suffice for the support of an indefinite number of generations belonging by turns to the two kingdoms.

By its synthetical nature vegetable nutrition must necessarily precede animal nutrition. It is as indispensable to this latter as the light of the sun is absolutely necessary to the development of plants; and this is not, as we may well believe, the least interesting aspect of its study, for it is probable that when we become well acquainted with every detail of the changes which contribute to the organization of mineral matter in the vegetable tissues we shall then be able, by making use of suitable agricultural methods, to assist the nutrition of plants artificially and at the same time to improve our own food, which is the object of all progress in agriculture.

We must also in this connection call attention to the present almost universal use of chemical fertilizers. This is certainly not the only improvement which we have a right to expect from scientific researches, and we shall now see that recent researches relating to the assimilation of liberated nitrates by plants are of a nature to make us look for others and perhaps equally important steps of progress.

Analysis shows that besides some mineral substances whose rôle is still very obscure, the cellular juice of all vegetables is formed of carbon and nitrogen combined with the elements of water—that is to say, with hydrogen and oxygen. These latter are evidently provided by the water which impregnates the earth, and as there is almost always a sufficient quantity of this, we need not occupy ourselves with it here.

Carbon, as we know, is taken by the plants from the carbonic-acid gas of the air, at least for the most part. Carbonic acid, like water, exists everywhere, and if I remind you that we have succeeded in transforming it into some of the sugars which exist so generally in the vegetable tissues, you will agree with me in saying that the great phenomenon of the assimilation of carbon by plants is at present understood only in its smallest details.

The mechanism of the assimilation of nitrogen is far from being as well understood even as that of carbon. We as yet know nothing of the chemical changes which cause this element to pass from a gaseous state to that of albuminous food; but its different modes of penetrating into the plant are well known to us, and we can affirm to-day that the atmosphere contributes as much as the soil to that portion of vegetable nutrition.

This fact, of which we shall shortly give the demonstration, was almost evident, a priori. In fact the soil contains only very small proportions of nitrogen. The store which it offers to us (scarcely 10,000 kilograms per hectare) is insignificant in comparison with the immensity of time; but in comparison with it the atmosphere contains an enormous quantity, about three-fourths of its entire volume; hence the idea of a continual circulation of nitrogen between its compounds and the air—in other words, between the air, the earth, and the living organisms—forced itself upon us, in the same way as the circulation of water between the ocean and all points of the earth obtrudes itself.

It is therefore the more remarkable that this conception of the subject has only quite recently been brought to light. Enunciated as a principle more than thirty years ago, it has only been taken into serious consideration in these latter years, after a series of researches which we are now going to pass in review.

But I should like first to establish, by experience alone, outside of all speculative ideas, the fact that the intervention of atmospheric nitrogen in the phenomena of vegetation is an absolute necessity. It will suffice for that purpose that I show a parallel, a sort of balance between the sources of gain and the sources of loss to the soil in nitrogenous compounds; it is clear that if this comparison shows us a difference in favor of the enriching of the soil then we need have no fear of seeing our soil become one day sterile; if, on the contrary, the losses are in excess of the gains from the exterior then we know that it must be receiving from the atmosphere the quantity of gaseous nitrogen equal to the difference. It is very easy to bring together the data for this great problem.

The most important cause of the decrease of nitrogen in the soil is unquestionably the crop taken from it each year; the amount of this loss is, however, very variable; a crop of cereals—of wheat, for example—takes from the soil about 50 kilograms of nitrogen per hectare; roots, beets, or others generally contain more; finally, certain kinds of vegetation, such as clover or lucern grass, take as much as 100 to 200 kilograms, and even more nitrogen per hectare annually.

Judging by these figures, we must conclude that by an average rotation of crops, where root vegetables, leguminous plants, and cereals are made to alternate one with the other, the earth loses every year by the fact of cultivation alone a minimum of from 60 to 70 kilograms of nitrogen in combination with other substances.

On the other hand, the soil is the seat of never-ceasing oxidations, caused by the free circulation of air within it; one of these phenomena of oxidation is that which acts upon the combustible nitrogenous substances held in reserve by the soil; under the simultaneous action of a free atmospheric oxygen and of a special kind of microbe, "the nitric ferment," discovered by Messrs. Schloesing and Müntz and described later by Winogradski, these substances are rapidly transformed into nitrate of calcium, or lime, which, by a happy combination of circumstances, is the favorite nutrition of most plants; this nitrate of calcium is extremely soluble and does not possess any affinity for the elements of the soil, like that existing between these same elements and ammonia, or, again, between them and the salts of potassium, whence it comes to pass that every infiltration of water takes this nitrate along with it, even to the depths of the lower soil, and from thence into the brooks, rivers, and thence into the ocean. In autumn, when the rains are abundant and when the denuded earth evaporates only a small quantity of the water which it receives, a veritable cleansing takes place systematically, and all the nitrates are carried far away as fast as they are produced.

The loss from this cause is enormous. In experiments made by Messrs. Lawes and Gilbert, at Rothamsted, for a great many years past these learned English agronomists have discovered that one hectare of soil planted in wheat loses in this way 50 kilograms of nitrogen—that is to say, as much as the wheat itself contains, or, again, a quantity equal to a manuring of 300 kilograms of nitrate of soda.

These figures are far from being exaggerated, and other observers, among whom I will mention Deherain, have obtained similar and sometimes even higher results than those of Lawes and Gilbert.

But this is not all. Boussingault found that rich soils continually give out ammonia in the gaseous state. These are the circumstances under which he discovered it: Having conceived the idea of analyzing a sample of snow which had remained for thirty-six hours in a garden bed, Boussingault found in it 10 milligrams of nitric ammonia per kilogram, while the same snow taken from a terrace very near there contained scarcely 2 milligrams. The difference of 8 milligrams was evidently due to the emanations from the earth. If we allow that this snow had a uniform depth of 10 centimeters and a mean density of 0.25 we shall find on a hectare a total weight of 250 tons, containing 2 kilograms of ammoniacal nitrogen which was given out from the soil during the short time that the snow lay on the ground.

By what coefficient must we multiply this figure in order to calculate the amount of annual loss which takes place upon an ordinary piece of arable land? We do not know at all, but we can affirm that the result of such a calculation would give more than 10 kilograms annually per hectare.

According to Schloesing, certain soils emit nitrogen in its free, uncombined state. This is particularly perceptible in soils which are badly ventilated and which contain a great deal of organic matter. The nitrogen then results from the decomposition of the nitrates existing in the soil, which decomposition is attributable, as Deherain and I have shown, to the development of certain anærobic micro-organisms.

If we leave out of the calculation this last cause of loss, which it is impossible to estimate and which is doubtless of little importance under ordinary circumstances, we shall find that a piece of arable land of average quality loses, by exhaustion from the crops, the infiltration of rain water and the ammonia which it disengages, an amount of nitrogen equal to a minimum of 120 kilograms per hectare annually. Therefore, as its soil contains scarcely 10,000 kilograms, its exhaustion would be complete in less than a century if these losses were not compensated by gains of about the same extent. Let us now examine into these causes of gain.

The soil receives nitrogen principally by the fertilizers given to it. Their proportion and richness are very variable, but experience shows that in general they do not suffice to supply the loss occasioned by cultivation alone. The difference which is found between the quantity of the nitrogen contained in the crop and that contained in the fertilizers is sometimes very great. Boussingault, to whom we are indebted for very precise researches on this subject, mentions a field where lucerne grass and wheat were cultivated, which having originally received 225 kilograms of nitrogen in the form of manure, furnished in a space of six years 44,000 kilograms of dry hay and 5,550 kilograms of wheat, straw, and grain, containing altogether 1,078 kilograms of nitrogen. The total excess, 854 kilograms, amounts in this case to a little more than 140 kilograms per hectare annually.

In general, this difference is less, but, I repeat, it is always in the same direction and may be estimated on an average at 30 or 40 kilograms annually; it remains then for us to provide for this excess, increased as it is by the losses caused by drainage of nearly 100 kilograms per hectare annually.

The most diverse and sometimes the most improbable reasons have been brought forward to account for this fact. It has even been suggested that the atmospheric dust acted as a natural fertilizing agent; but let us go on to more serious hypotheses. It has been thought that the rain water in taking from the air its soluble compounds might furnish a certain proportion of ammonia or nitric acid to the soil. Analysis has shown that this proportion is extremely small; water caught in a rain gauge contains, indeed, only a mere trace of nitric substances, scarcely 2 grams of ammonia and less than 1 gram of nitric acid per cubic meter, which corresponds to a maximum of 5 to 8 kilograms of nitrogen a year per hectare. This quantity would, then, be barely sufficient to compensate for the losses due to the gaseous ammoniacal emanations from the earth.

On the other hand, Schloesing admits that the earth, and the plants by means of their foliage, directly attract the ammonia existing in the air. This ammonia, according to the learned agronomist, is constantly emitted by the sea water, which thus restores to us under another form the nitrogen which is constantly being brought to it by the drainage water.

It is certain that humid soil can attract the ammoniacal vapors, but it is also certain, as proved by the experiments of Boussingault, that such soil can also emit them; there is, therefore, a tendency to establish, in this respect, an equilibrium between the soil and the atmosphere, the result of which is probably not far from a perfect compensation.

If, then, it is true that the leaves of plants can assimilate gaseous

ammonia, we know that the average air contains extremely few nitric compounds. According to the analyses made first by G. Ville and later by Schloesing, the atmosphere contains at most from 25 to 30 grams of ammonia per cubic kilometer. It would, therefore, be necessary, in order to provide for the loss which we have just spoken of, that the soil and its plants should absorb in the space of a year all the ammonia contained in a column of air having the surface of the field for its base and a height of 400 kilometers under a constant pressure equal to the barometric height at sea level. This is about 50 times the quantity required for the carbonaceous nutrition of a crop weighing when dry 5,000 kilograms.

Such an hypothesis is inadmissible; besides, if it were correct we should not be able to understand why a crop of gramineæ cultivated in a sterile soil, aided only by a small quantity of fertilizer, never contains more nitrogen than was contained in the seed and in the manure given to it.

The above-mentioned deficiency, then, always remains, whichever way we look at it. Let us see if it is real or if the soil receives any compensation.

Since the application of chemical analysis to agricultural researches no decrease in the average fertility of our arable lands has been discovered; on the contrary, many have become richer in consequence in the improvements in the methods of cultivation and, above all, in the regular use of fertilizers. They have therefore become more productive, and the average yield of wheat in France, which, at the beginning of this century, was only at the rate of 11 hectoliters to the hectare, has gradually risen to 15 and 16 hectoliters.

This fact alone is in direct opposition to the hypothesis of a gradual impoverishment of the soil. Here are other objections more striking still:

The forests, the meadows high up on the mountains, which are never manured, have from the remotest ages furnished, in the form of wood, milk, cheese, wool, or viands, quantities of nitrogen inferior, no doubt, to what it would be under a more intense cultivation, but constant and without the soil which produces them showing the least sign of exhaustion.

This virgin soil is even more fertile than our best arable lands. In Auvergne Truchot saw meadow lands containing 9 grams of combined nitrogen per kilogram; Joulie mentions some which contain 1.5 grams, and 1.8 grams per 100 of nitrogen, while land of good quality on which cereals were cultivated yielded ordinarily ten times less. Finally, and it is with this that we terminate this part of our subject, certain plants, among which we must place in the first rank grasses of natural or artificial meadows, cause a progressive enriching of the soil even in the absence of every species of fertilizer, and notwithstanding that they contain more nitrogen than other crops, said to be exhausting, such as the root plants and cereals.

Practical agriculture has long since demonstrated this fact in regard to leguminous plants; all farmers know that wheat planted after a crop of clover or of lucerne grass yields a much better harvest than it would have done under the most copious fertilizing, and it is for this reason they speak of the leguminous plants as ameliorators or natural fertilizers of the soil.

The action of natural meadows in enriching arable soils is of the same nature; here follow some curious results on this subject which I have borrowed from the works of Messrs. Lawes and Gilbert and those of Déhérain.

In 1856 Messrs. Lawes and Gilbert transformed into meadow lands a portion of the domain of Rothamsted, which for a long series of years had been used only for raising grains. The soil contained then 1.52 grams per 1,000 of nitrogen; it was manured regularly and in what would be called excessive doses in such a way that the nitrogen of the fertilizers always exceeded that of the crop by about 15 kilograms every year.

It is evident that they could not pretend with this small surplus to compensate entirely for the losses caused by the drainage; nevertheless the soil, instead of becoming impoverished, was constantly enriched, and at the end of the year 1888 its proportion of nitrogen was 2.35 grams per 1,000—that is to say, 0.83 gram more than at the beginning. This difference corresponds to a total of 1,813 kilograms to the hectare for the entire time that the experiment lasted—that is to say, an annual gain of 50 kilograms per hectare.

The phenomenon is moreover progressive, and nothing in its rate gives any reason for supposing that it is approaching its limit.

At the experiment field of Grignon, my learned instructor, Déhérain, observed similar facts. From 1875 to 1879 he raised beets and maize for fodder upon a piece of land freshly cleared of lucerne grass and containing a proportion of 2.05 per 1,000 of nitrogen. In spite of the fertilizers given to it during that time, the land became rapidly impoverished, no doubt from excessive nitrification, and in 1879 its fertility had declined to 1.50 grams—that is to say, to about three-quarters of its former value.

The maize was then replaced by French grass [sainfoin] from 1879 to 1883, then with a meadow of Gramineæ from 1884 to 1888, inclusive, this time, however, without giving it any kind of fertilizer. The soil then began gradually to increase in fertility and has now returned to its former state of richness.

Another experiment very similar to the preceding, but in which they had not manured the soil since 1875, gave nearly identical results.

If we admit that at Grignon the soil of a hectare weighs on an average 4,000 tons, we see that in ten years, from 1879 to 1888, the soil gained under the influence of the prairie grass alone 1,920 kilograms of nitrogen, to which we must add 1,210 kilograms taken away by the crops, or a total of 3,130 kilograms, or more than 300 kilograms a year per hectare.

Here again the limit is far from being attained, and it can be easily understood that soils subjected to this treatment would in time come to contain 10 grams per 1,000, or a hundredth or more of nitrogen, like the meadows mentioned by Messrs. Truchot and Joulie.

It is clear that this natural phenomenon can not be owing to the contributions of nitric compounds brought by the rain water or by the atmosphere, for, even by attributing to these sources a power much beyond that which we have recognized as belonging to them, all plants should then behave in the same manner; whereas we have seen that we must distinguish between the cereals which impoverish the soil continually and the leguminous plants which always enrich it.

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Lawes and Gilbert have thought to find an explanation of the ameliorating influence of leguminous plants on the soil in the fact that plants of that kind generally have very long roots and are therefore able to go much deeper in search of their nourishment than the depth at which the roots of the Gramineæ are developed; the enriching of the earth would therefore be due to the organic débris that cultivation leaves there after the harvest, the nitrogen in which had been taken from the subsoil. The defect of this view is that the fertility of the soil decreases rapidly as the depth increases, and in the majority of cases the subsoil contains only such very insignificant quantities of nitrogen that it is impossible to conceive that any plant could be nourished by it, particularly a leguminous plant which contains in its tissues five or six times more nitrogen than does a Gramineæ.

In a word, the most simple observations of practical agriculture show us that the amount of nitrogenous substances furnished by nature would not suffice for the requirements of vegetation; it is therefore indispensable that gaseous nitrogen should interpose directly, and that, too, to an important extent, at least for the cultivation of leguminous plants.

Mr. G. Ville proved this experimentally as early as 1849, and he has not ceased repeating it since then, in spite of the systematic opposition of most physiologists and agronomists.

The primitive experiment of Mr. G. Ville has now become, by recent labors in connection with it, an established fact. Allow me, then, to describe it briefly, dwelling principally upon its results.

In a sterile soil, containing at least 1 kilogram of calcined sand, various leguminous plants, such as peas, beans, lupins, and others, were sown; then were added some nutritive substances, either mineral substances alone or a mixture of mineral fertilizers with a small quantity of nitrate of soda, the object of which was to aid the young plant to pass safely over the critical period of its growth, or, in other words, the time when, having exhausted the alimentary reserves provided for it by its cotyledons, it must henceforth nourish itself with substances entirely inorganic.

The plants were watered with pure water free from ammonia; every precaution was taken to assure the aeration of the soil; finally the plants were kept in as pure an atmosphere as possible, either in a glass cage, where from time to time carbonic-acid gas was introduced, or, what is preferable in the open air, far from the laboratory, and, in general, far from everything which could contribute to the disengagement of ammonia.

Under these conditions, and particularly when the soil received no nitrogenous fertilizer, the plant remained puny at first, suffering from what the German physiologists have called "nitrogen famine." Some plants even do not survive this painful stage of their existence, but die without having sensibly increased their dry weight; others, more vigorous, yield a mediocre crop; finally some, by the side of other dying stalks, become suddenly very flourishing. Upon the first stalk, which up to that time has been lank and without strength, a new stalk seems in some way to graft itself—stronger, stiff, turgescent—which soon becomes covered with broad, well-developed leaves of a green that are entirely different from the yellowish tint of the

first leaves, and this plant is soon as full of flowers and fruit as if its entire growth had taken place in a soil of excellent quality. The crop is then very good. It contains a large quantity of nitrogen, which evidently could only come to it from the atmosphere.

This recrudescence of vegetation shows itself at a time when the weight of the plant is eight or ten times that of the seed, and similar contrasts are often observed in two stalks grown in the same pot, which are, therefore, consequently in the same soil, under the same conditions, the seeds being as similar as possible.

In a word, the experiments of Ville teach us two unforeseen and equally remarkable facts. The first and most important is that a leguminous plant can live and prosper in a soil entirely destitute of all nitrogenous compounds, thus necessitating the direct assistance of the atmosphere; the second is that all seeds of the same kind are far from behaving in the same manner, whence it results that the course of the experiment is eminently uncertain.

With plants of the family of the Gramineæ nothing similar takes place. The results are absolutely invariable; the crop is zero if the soil does not contain nitrogenous substances. It increases regularly with the quantity of fertilizer, and each seed produces about the same weight of dry material.

The irregularity of the results given by the leguminosæ under the same conditions shows that there could be in this case no question as to the accidental gains of nitrogen, attributable to ammonia or to atmospheric dusts, or to the water used in watering; the fact had been discovered, but its true cause had escaped the discoverer.

G. Ville, convinced of the correctness of the positive results obtained by him, was certainly right in concluding from them that certain kinds of plants attract carbonic-acid gas, but he was not master of his experiment. Other observers also tried to repeat it after him, but did not succeed. Boussingault, in particular, having placed his plants in spaces that were too restricted to allow of the free development of their roots, only obtained stunted plants weighing scarcely four or five times as much as the seed and containing no more nitrogen than the latter, because they had never attained the second stage of their growth.

In consequence Boussingault, who, however, had several years before obtained results similar to those of Ville, thought himself justified in laying down as a principle that vegetables, no matter to what variety they belong, are always incapable of taking even the smallest quantity of nitrogen from the air.

I shall not dwell upon this discussion, which has remained celebrated and which is very much to be regretted, inasmuch as the result of it was that by deterring those students who would have liked to pursue the study of the question further its definitive solution was retarded for thirty years. I only wish here to confine myself to a single point in it, which is that the fixing of free nitrogen by plants was observed already in 1850, with all the characteristics of irregularity belonging to it and as they have been again described in recent physiological researches of German physiologists.

I now come to the recent works, and I shall commence by those of Berthelot, in which we shall be confronted by an entirely new idea—that of the interrelation of microscopic life and the phenomena of vegetable nutrition.

The first experiments of Berthelot date from 1885. Their object was the fixation of nitrogen by denuded soils, leaving out, consequently, all idea of vegetation. The soils used for the purpose were chosen from among the poorest in nitrogen. They were sandy clays taken from Meudon or from Sevres, below the level of the quarries, or, again, porcelain earths, crude kaolins not yet crushed in the mills.

These soils, four in number, were submitted to five series of experiments. They were left to themselves in glazed pots, either within a well-closed room or in the open air in a meadow, either without shelter or under a little glass roof, merely to protect them from vertical rains, or on the top of a tower 29 meters above the ground and without any shelter, or finally, in corked flasks, so as to exclude all possibility of absorption of ammoniacal or nitric vapors. In the fifth series of experiments the same soils had first been exposed to a temperature of 100°, so as to destroy from the first all the organic germs that they might contain. The quantity of nitrogen, determined with great precision in each of the samples at the very beginning of the experiment, was again analyzed after two months, and again after remaining five months under the conditions indicated above, allowance being made for exterior additions attributable to air and to the rains when the pots were not sheltered.

The results obtained did not leave the slightest doubt. In every case in which the earth had been left in its normal state it had become enriched, and sometimes to a very great extent more than doubling the quantity of the initial nitrogen; when, on the contrary, the soil had been sterilized by heat, it became constantly more impoverished. In a word, then, poor clayey soils are able to absorb atmospheric nitrogen directly. This absorption is not accompanied by any increase in the previous proportions of ammonia or of nitric acid; it is, then, due to the formation of complex organic substances. Finally, it is the work of a micro-organism, since it ceases to be produced as soon as the soil has been sterilized.

To what sum per hectare does such a fertilization correspond? Berthelot estimates at 20 or 30 kilograms for a thickness of one decimeter of soil. Hence for a thickness of 0.35 meter it would suffice to compensate for the losses inherent to drainage and cultivation; but before going further it is well to remark that the experiments which we have just described relate to particularly poor soils, which are therefore of a nature to enrich themselves. In truly arable soils, averaging from 1 to 2 grams of nitrogen per kilogram, Berthelot has also observed a perceptible fixing of nitrogen, which, however, is relatively less than in sandy clays, and it is probable that this phenomenon would cease to be apparent after a certain limit, which, doubtless, is not very high.

The conditions which, according to Berthelot, apear the most favorable to the fixing of nitrogen by the naked soil are:

1. The presence of a quantity of water comprised between 3 and 15 per cent of total saturation;
2. A sufficient porosity to assure the free penetration of air throughout the whole mass of earth;
3. A temperature of between 10° and 40° C.

These conditions define the microbe which secretes or fixes the nitrogen as an aerobic organism (i. e., one that feeds on the atmosphere or is aerobiotic).

Except under the conditions previously pointed out, the phenomenon is no longer seen, and, in general, it is limited by the inverse action—that is to say, by a continual dissipation of nitrogen or ammonia into the gaseous state.

Whatever may fix this limit, the fact observed by Berthelot is of the first importance. It is the first time, in fact, that we see the fixation of nitrogen in naked soils clearly stated; especially is it the first time that we see a cause experimentally defined and demonstrated without any reasonable doubt stand forth in the midst of such complex phenomena. This cause, as we have seen, is no other than the development of inferior organisms[a] whose nature it remains for us to define more precisely.

This was an entirely new idea and one which could not fail to produce its fruits. We shall therefore see researches rapidly multiply and lead their authors to more and more definite conclusions.

A. Gautier and Drouin verified first, in artificial soils, the principal results stated by Berthelot; they employed a mixture of siliceous sand, pure limestone, kaolin, and neutral phosphate of potash, to which they added, in particular cases, humus, humic acid or humates, or oxide of iron. This mixture, with the addition of a little nitrate of potassium, seems to be very favorable to the development of leguminous plants.

Under these conditions Gautier and Drouin recognized that the fixation of nitrogen always takes place in mixtures which have received organic matter; in its absence, on the contrary, there is always a loss. Organic matter appears, then, to be an important factor in this great natural phenomenon. It acts, doubtless, by promoting the nutrition of the microbe which fixes the nitrogen.

I will now indicate other experiments, repeated by Ville and Boussingault, in which we shall see the effect of the intervention of vegetation.

Berthelot first undertook a series of cultivations of leguminous plants in large pots which were left in the open air, either with or without shelter, or kept under a glass cover, care being taken to supply the plants with the carbonic acid necessary to their growth.

The soil, the seeds, the gathered plants, the drainage water and rain water were all analyzed with the greatest care in order that an exact comparison might be established between the initial and the final nitrogen.

Under the glass cover the fixation of nitrogen was very weak, because the plant, under these circumstances, did not reach its normal development, but in the open air the quantity of nitrogen fixed was, in every case, superior to that fixed by the soil alone.

For example, the tare tripled this quantity; the crop furnished by a mixture of kidney-vetch and *Medicago lupulina* contained ten times more nitrogen than was contained in the seed bed; a crop of lucerne grass contained sixteen times more, and this excess of nitrogen was always found more abundantly in the roots than in the leafy parts of the plant.

The soil enriched itself, but in a less degree than plant and soil together; therefore active vegetation promotes in an enormous degree

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[a]Aerobies: Micro-organisms which live in contact with the air and require oxygen for their growth. Anaerobies: Micro-organisms which do not require oxygen, but are killed by it.

the assimilation of free nitrogen by the earth, a fact which is in conformity with all observations made in extensive farming operations. The distribution of this nitrogen in the plant shows that it enters through the roots, doubtless in consequence of microbic intervention. Finally, if we sum up the excess of nitrogen thus found in the crop and in the soil, together with the drainage water, we should find, according to Berthelot, 300, 500, and even 700 kilograms per hectare, a part of which evidently remains in the ground as roots, if we are contented to gather only the portion of the crop which is above ground, as is generally done in practical agriculture.

Thus it is that there results the progressive enriching of arable soils under the ameliorating or improving action of leguminous plants; thus also results the possibility of continuous cultivation of certain crops, such as meadow grass or forest trees, without fertilizers and without the earth becoming impoverished.

Joulie arrives at very similar conclusions from experiments of the same kind. The cultivation of buckwheat and of hay on a piece of land in the department of Dombes showed in two years a fixation of nitrogen equal to more than 1,000 kilograms per hectare. The mean of twelve experiments, one only of which showed a loss of 0.0136 gram per 1.5 kilograms of soil, showed a fixation of about 500 kilograms of nitrogen per hectare in a space of two years.

A little later Messrs. Gautier and Drouin also found, under the influence of the cultivation of common beans, an enrichment of their artificial soils which, as they estimated, corresponded to 185 kilograms per hectare for a single crop only.

Finally Pagnoul, after having recognized that the soil alone is capable of directly fixing the nitrogen of the air, found like the preceding authorities that the enrichment of the soil took place to a considerable extent even with a simple crop of grass or clover. For the latter he found fixations amounting to 500 and 900 kilograms of nitrogen per hectare.

We see that all these results are in absolute accord with each other, and, what is worthy of remark, they are of the same order of magnitude in experiments made by several different persons. Nothing is wanting to them but the direct control to be obtained by a change in the composition of the gases in which the plants grow.

From this point of view the experiment is particularly difficult to carry out. The plants must be kept constantly in closed vases in a confined atmosphere, consequently in the presence of vapor of water at its maximum intensity, which seems to be an eminently unfavorable condition; besides, it is necessary to be able to measure the volumes of the gas contained in the apparatus, to analyze them with scrupulous exactitude, and, finally, to promote the chylophyllic nutrition by regular additions of carbonic acid without allowing the proportion of oxygen to vary too greatly. Schloesing, jr., and Laurent have triumphantly overcome all these difficulties. In a memoir published in 1890 these clever experimentalists state that in the space of three months three seeds of dwarf peas sown in a soil destitute of nitrogen, but prepared in such a manner that the absorption of nitrogen could easily take place, absorbed from 26 to 29 cubic centimeters of nitrogen, weighing 32.5 milligrams and 36.5 milligrams, respectively. This nitrogen, measured volumetrically, was found again (with all the precision requisite in so delicate a research) partly in the soil,

which was enriched on an average to 12 milligrams, partly in the plants, which had gained 20 to 30 milligrams, although, owing to the narrow space in which they were confined, they were not able to attain their full development.

This last proof appears to have finally closed the discussion formerly inaugurated by Boussingault and which had not been completely closed by the analytic results explained above.

Thus a few years have sufficed to definitely decide this theory of a direct assimilation of nitrogen by plants, first enunciated by Ville.

What, now, is the mechanism or modus operandi of this assimilation? We have just seen how Berthelot was led, by certain peculiarities of his experiments, and, above all, by the complete cessation of all fixation of nitrogen in soils that had been subjected to a temperature of 100°, to admit that nitrogen is assimilated directly by certain inferior organisms which force it into organic combination; but we have also seen that the fixation of nitrogen by naked soils is always weak and generally insufficient for the necessities of a normal vegetation.

It is true that when the aid of a leguminous plant is invoked the fixation becomes more active and may become powerful enough to compensate alone for all the known causes of loss; but how, then, are we to account for the difference in this respect found between the Leguminosæ and the Gramineæ? Shall we be forced to admit that the Leguminosæ are able, by themselves, to assimilate gaseous nitrogen, by a power possessed by them which is wanting in the other species?

Berthelot has concluded, from his researches upon this subject, that in the development of leguminous plants there comes into play some micro-organism which facilitates the fixation of nitrogen upon the root of the plant, or rather upon the mass formed by the root and the soil, intimately connected one to the other; but this idea could not be definitely adopted unless the existence of such a microbe were proved by experiments. This result is fully demonstrated by a series of very remarkable experiments made by Hellriegel, Wilfarth, Frank, Prazmoffski, and others in Germany, and which have been most successfully verified by Bréal, Schloesing, jr., and Laurent in France, and, finally, by Lawes and Gilbert in England.

Before proceeding to explain these researches I must call attention to a well-established fact which had been well known for a great many years, although no one before Hellriegel and Wilfarth ever thought of seeing in it anything more than a phenomenon of nature.

When we examine the roots of a leguminous plant grown in good soil we always see irregularly disposed on them tuberculous enlargements, a kind of nodosity [node, nodule, knot, or knob] formed of a special tissue and apparently quite accidental. Examined with a microscope the interior of these excrescences appears to be filled with corpuscles of varying forms, always animated with the "Brownian" movement, although they have sometimes a movement of their own. These assume various shapes; sometimes they are like simple rods similar in form to certain bacteria; sometimes they have the appearance of vegetable coralloids and take the branched T or Y form more or less ramified.

Botanists have for a long time discussed the nature of these excrescences, but at present it seems to be generally admitted that, morpho-

logically considered, they constitute roots modified by the penetration of an exterior organism. Under no circumstances have we a right to consider them as a natural production of the plant, because, as Prazmoffski has shown, plants that are kept protected from all causes of contamination are always free from them; while, on the contrary, their roots become covered with a multitude of nodosities when plunged into a liquid where a tubercle has been crushed or when they are replanted in any sort of soil that is watered with a similar liquid.

The artificial infection of the roots of leguminous plants, as enunciated a dozen years ago by Prillieux, has been verified by Hellriegel and Wilfarth, Prazmoffski, Laurent, and Bréal. This latter investigator has even discovered that we may certainly assure the formation of a tubercle by pricking the root of a leguminous plant with a needle which had been previously inserted into a tubercle growing on another root.

There remains no doubt of this fact: The nodules of the Leguminosæ have a microbian origin. The organism which causes them has received the name *Bacillus radicicola;* Laurent places it beside the *Pasteuria ramosa*, between bacteria proper and the lower fungi. Essentially aerobic in its nature, it resists all freezing and drying; but a temperature of 70° C. is sufficient to destroy it. It has been successfully cultivated in bouillons made of peas, or of beans, supplemented with gelatine and asparagine, or even in a solution of phosphate of potash and of sulphate of magnesia, to which is added a little sugar, but without any nitrogenous substance whatever. This organism grows in such liquids, preserving its habitual ramified forms, but without producing any true spores.

As to the tubercles themselves, they have until lately been considered as morbid productions, useless to the plant. Some authors have sought to see in them organs either of reserve or organs for the transformation of the albuminous substances necessary for the nutrition of the plant; others—and this is the general opinion at the present time—look upon them as the result of a symbiosis—that is to say, of an extremely intimate association between the root of the plant and the microbe living with it, entirely different, however, from the action of the ordinary parasite.

Hellriegel and Wilfarth were the first to discover a connection between the development of bacteroidal nodosities and the assimilation of gaseous nitrogen by the Leguminosæ. After having observed that in a culture of peas the most vigorous plants were always those that possessed the greatest number of tubercles, these investigators carried out many series of systematic experiments in glass jars containing 4 kilograms of quartz sand, to which they added certain of the principal minerals necessary to vegetation, such as phosphoric acid, sulphuric acid, chlorine, potassium, etc., and in certain cases a small quantity of nitrogen in the form of nitrates.

In these jars, which were exposed to the open air, they sowed barley, oats, and peas. The results were exactly the same as those formerly obtained by Ville and Boussingault.

In soils destitute of nitrogen the crop of cereals (barley and oats) is nearly nil, but it increases in approximate proportion to the dose of nitrate added, so that for each added milligram of nitrogen there is an increase of crop equal, on an average, to 95 milligrams of vege-

table matter. Thus we see that all the experiments agree with each other.

In the case of peas the results are entirely different, for we see, as in Ville's former experiments, that by the side of a plant weighing less than a gram there will be another plant weighing 10 or 15 or 20 grams, and even more, without its being possible to attribute the difference to any apparent influence coming from the outside. There is a régime of absolute irregularity, and an examination of the roots shows that the irregularity is proportional to the presence or absence of tubercles on the roots, whence arises the connection above mentioned.

It now only remains for us to distinguish between cause and effect. Is this appearance of these nodosities in itself merely a consequence of the greater vigor of the plants, or ought we, on the contrary, to see in these very tubercles the origin and cause of that greater vigor? The following experiment will show us which of these two hypotheses is correct:

When to the same soil of sterile sand which served for the preceding experiments only 5 grams of good arable soil dissolved in 25 cubic centimeters of water was added, the peas grew in a natural manner and produced, on the average, from 15 to 20 grains of dried crop. Each stalk contained, on an average, 450 milligrams of nitrogen, although there were scarcely 10 contained in the soil. In every case there was a fixation of nitrogen in the gaseous state amounting to nearly half a gram.

Under the same conditions a seed of lupin produced a crop of from 42 to 45 grams, containing more than 1 gram of nitrogen.

French grass (sainfoin) produced the same results, and in all cases we see that the roots of these different plants are abundantly provided with tubercles; but if the artificial soils and the solutions of earth employed in these experiments have been sterilized by the action of heat the plants remain invariably puny and produce less than 5 grams of dried material per stalk. In this case the tubercles are always wanting.

Under cover, in pure air to which a little carbonic-acid gas has been added, the results are a little less favorable than in the open air, but they still show an important fixation of nitrogen in the case of Leguminosæ infected with bacteria.

These principles, then, represent the determining cause of the phenomenon, and the systematic addition to the soil of appropriate germs will enable us hereafter to reproduce at will the experiment of Ville, which was formerly attended with such uncertain results.

In the Museum of Natural History, Bréal has obtained results similar to those of Hellriegel and Wilfarth. In one of his experiments a pea containing 9 milligrams of nitrogen, in a soil of poor gravel, but into which bacteria had been sown, produced a plant weighing 103 grams in a green state, 32.3 grams when dried, and containing 358 milligrams of nitrogen—that is to say, 40 times as much as the seed. The pea vine, which was 1.40 meters long, produced 14 ripe pods; the gain in nitrogen thus realized corresponds to about 255 kilograms per hectare.

In another experiment, a small plant of lucerne grass provided with tubercles and weighing 10 grams, and likewise in a soil of sterile sand, gave a crop weighing 332 grams when green, 85.5 when

dried, and containing 1.733 grams of nitrogen. The total fixation of nitrogen amounted to 1.715 grams for the surface of the flowerpot, or 274 kilograms per hectare.

It is a remarkable fact that before the formation of the fruit the nitrogen in the Leguminosæ is, by preference, localized in their roots. This fact is due to the great richness of the tubercles with which they are covered. Bréal found in the nodules of several plants, such as kidney beans, peas, lupins, lentils, acacia, etc., as much as 7 parts of nitrogen to a hundred of dried material, even when the fibers of the roots never contained more than 2.5.

Another fact, not less interesting, brought to light at the same time by the experiments of Hellriegel and Wilfarth, is the difference shown by arable soils in their capacity to initiate the appearance of tubercles upon the roots of leguminous plants. Some of them are very efficient in this respect; others are much less so. There are even some soils which are more favorable to the production of tubercles in certain species of plants than in others. This is a fact very difficult of explanation, for the solution of which further and bacteriological researches will be necessary, because variations of this kind can only be due to a difference in the microbe itself, the penetration of which into the roots produces these nodules.

In the experiments of Hellriegel and Wilfarth the sowings were made with the washings from earth, containing, as we know, a multitude of micro-organisms having different functions. Some of them, it is true, were made with a liquid containing a little of the white substance which comes from the nodules when they are crushed, but all precautions had not been made to get rid of the germs which the water itself might have contained, or which might have been brought either by the young plant or by the atmospheric dusts.

It was therefore necessary in order to be sure that the fixation of the nitrogen was really due solely to the bacteria of the nodule to repeat the preceding experiments with all the precautions required by microbic researches.

This work of revision was carried out with scientific rigor by Prazmoffski, in Cracow, with great success.

The vessels used for growing the plants were provided with a cover, which fitted tightly and had four holes pierced in it. One of these holes, made in the center, permitted the young plant to pass through it. The three others allowed of watering and of the passage of a current of pure air. All these holes were closed with plugs made of a sterile wadding, which prevented the entrance of all germs of exterior organisms.

The soil was formed of about 3,500 grams of siliceous sand, previously washed in boiling hydrochloric acid, then in water, and finally heated red hot. Pure mineral fertilizers without any nitrogen whatever were then added to it.

The whole mass was then sterilized by being heated for at least two hours from 140° to 150° C.

In these vessels peas which had been previously sterilized were sown. To effect this they were first plunged into a solution of corrosive sublimate, then washed in alcohol, which latter was finally set on fire and burned upon the seed itself.

Some of the vessels received also bacteroidal germs contained in a nonnitrogenized bouillon culture liquid.

But in spite of all of these precautions it was not always possible to prevent the penetration of foreign organisms to the tubercles. In a certain number, however, of the successful experiments in which the bacteria alone remained in contact with the roots the results obtained were identical with those obtained by Hellriegel and Wilfarth. There was a fixation of nitrogen in all the pots in which the bacteria were sowed, and in those only.

Thus in a sterile soil, without microbes, a pea containing 12 milligrams of nitrogen produced only 1.166 grams of dried crop, in which 13.2 milligrams of nitrogen were found, or about as much as was contained in the seeds sown. Where microbes were present, on the contrary, the dried crop weighed 3.544 grams and contained 82.6 milligrams of nitrogen. Therefore the bacteria had given to the plant the faculty of taking from the air 70 milligrams of nitrogen independently of all other microbic intervention and under the same exterior conditions.

By using water in the place of sand Prazmoffski also obtained the same results. Some peas grown in a nutrient solution without nitrogen and sterilized gave only 9 milligrams of nitrogen, whereas others grown in a similar liquid but supplied with bacteria gave from 26 to 82 milligrams.

These experiments then verify in the most complete manner the views of Hellriegel and Wilfarth; the fixation of nitrogen by the leguminoseæ is a consequence of their symbiotic union with an infinitely small organism whose germs are profusely scattered abroad and which enables these plants to grow sometimes with vigor without any artificial inoculation in soils destitute of all nitrogenous food.

It was these germs which enabled G. Ville to first observe the fixation of atmospheric nitrogen by these same plants, and it was their irregular dissemination which caused the inequality in his experiments, and if Boussingault found it impossible to obtain the same results it was simply because he cultivated his plants under such conditions that they could not acquire sufficient vitality to profit by their union with these bacteroids.

In effect at the beginning of vegetation in soils without nitrogen, but into which microbes have been introduced, an interval of stoppage of growth has been observed, so complete as to make us fear a rapid decay of the plant, and this period of intermission always coincides with the appearance of the tubercles on the roots of the plants. At this time the invading organisms derive their nourishment from the juices of the young plant; they exhaust it, and if the latter has not the strength to resist this invasion, which then constitutes a sort of parasitism, if its roots are not able to develop freely, or, again, if its leaves remain in a badly ventilated atmosphere, always saturated with aqueous vapor, the plant will inevitably perish.

If, on the contrary, it can resist, it will very soon gain the advantage; it then takes from the bacteria the nitrogenous matter which they contain and compels them to form more of it from the nitrogen which surrounds them. Doubtless on its side the bacteriod profits as much as the plant from its symbiosis; it is probable that it receives from the latter hydrocarbons—sugars or others—in exchange for the albuminoids which it gives to the plant, and thus it is that this union may exist until, finally, the moment arrives when the plant, having

attained its full growth, entirely consumes the tubercles in order to assimilate them and thus form its seed.

It is then, in short, by means of their roots that the leguminoseæ draw the nitrogen from the air, and this conclusion agrees with the well-known fact that a living leaf is incapable of modifying the volume of nitrogen into which it may be plunged, and that it is the root which in the first stage of vegetation always shows the greatest richness in nitrogen.

It is the remains of these roots and the rupture of the tubercles that are carried on them which determine the enrichment of the soils of meadows, and the dispersion of the germs of the microbe that fixes the nitrogen.

It has been objected to the conclusions of Hellriegel and Wilfarth that up to the present time it has been impossible to observe a fixing of nitrogen by the bacteroids alone independently of their symbiotic alliance with a leguminous plant. This is true, but it must be remembered that the obtaining of such proof is fraught with great experimental difficulties; the micro-organism, cultivated, we will suppose in a place where there is no nitrogen, will certainly take the nitrogen from the air, but not more than is necessary for the formation of its tissues; that is to say, an extremely minute quantity, for the microbe itself weighs very little, and thus it happens necessarily that the phenomenon remains undetected by even the most delicate methods of analysis.

In order that the absorption may be manifest it would be necessary that we should be able, as the Leguminosæ actually are, to take from the bacteroids their nitrogenous substance as fast as it is produced, or that it should be cultivated in such quantities that the dry weight should attain measurable quantity. Shall we ever discover the means of making this experiment? It is impossible to say at this moment, but what we can affirm is that it is not correct to conclude, as certain authorities have done, that the bacteroids are incapable of fixing nitrogen gas when alone, basing their objections solely on the ground that up to the present moment it has not been possible to prove such a fixation of nitrogen.

Besides, atmospheric nitrogen is but a part of the complete nourishment of the Leguminosæ; since, in common with other species of plants, they can assimilate the nitrates and ammoniacal salts, although in a less degree.

When a pea, a bean, or a lupin grows in a fertile soil it never shows that tendency to perish due to a "famine of nitrogen," which characterizes the same plants in a sterile soil; the plant's vitality is great at the beginning of its growth and it is for this reason that, in order to insure the success of his experiment, G. Ville advised that a small quantity of nitrogenous fertilizer be added to the mineral substances that are given to the sand in which the plants were cultivated; in this case, however, the tubercles are less abundant and the sum total of the nitrogen borrowed from the atmosphere is lower.

If this bacteroidal action be not the only one capable of furnishing to leguminous plants the nitrogen necessary to them, there is evidently no occasion to draw an absolute line of demarcation between these plants and others, which being less qualified to associate themselves with the microbes (doubtless because the medium that these offer to them is less favorable to their development) derive, therefore,

more benefit from nitrogenous fertilizers. Between the Papilionaceæ and the cereals, which occupy extreme positions in regard to the capacity for fixing atmospheric nitrogen, there exist probably other intermediate species capable of exercising the same function in every degree. These latter must be less improving to the soil than the Leguminosæ, but they must assuredly be less exhausting than wheat, Indian corn, or beets, and it is impossible to explain otherwise than by reasons of this kind the continued growth of forests and meadows which continue incessantly to furnish crops in soils which never cease to be much richer than our cereal soils, although they never receive any fertilizers.

According to Ville, the Cruciferæ in particular are capable of taking a part of their nitrogen directly from the air. On the other hand, we know that the roots of certain species of forest trees form a symbiosis with some kinds of mushrooms which are not yet well known and which perhaps act in the same way as the bacteroids of the nodules. I shall not, however, insist upon facts which are liable to discussion and which require to be studied more minutely and with all the care which has been bestowed upon the study of the Leguminoseæ.

I have now only one more point to examine in regard to this question, a point which, although still involved in obscurity, is nevertheless very interesting. All planters are well aware of the fact that a leguminous plant can only be grown for a few years in the same soil. After being very flourishing for a short time a field of clover or of lucerne dwindles away, the crops rapidly become less abundant, and finally the soil is invaded by the Gramineæ, which rapidly transform the artificial meadow into a natural one, unless precautions have been taken, by clearing the land, to prevent the phenomenon. To what can we attribute this spontaneous transformation? The microbe has had at its disposal all the elements necessary for its growth and its dissemination. Why does it cease all of a sudden to exercise its favorable influence? Perhaps there is in this something very important, which I can, however, only express in the form of an hypothesis, but which, nevertheless, I think is worthy of having your attention called to it. Pasteur has shown us that certain inferior organisms change their nature, lose their noxiousness, or become more virulent if they are made to pass from one species of animal to another. May it not be that the bacterium of the nodules undergoes also a modification by its prolonged contact with the roots of the Leguminosæ and that it would be necessary for it, in order to resume its former functions, to pass to some other species of plants—in other words, to change its surroundings? Experience alone will solve this question. I will content myself here with putting it before you.

Scientific researches sooner or later always find their practical applications; these that I have had the honor of bringing before you can not fail to render important services to agriculture. The "restoring" part played by the Leguminosæ is known to all agriculturists; it has become an axiom of agriculture and forms the basis for the rotation of all crops; but after the experiments which we have just passed in review it assumes for us a strictly scientific character which it did not possess before. The modus operandi of the process has been determined, and by a simple modification of the processes of cultivation now in use, by assigning a still more extended

sphere to leguminous plants, it will be easy for us to profit by this newly acquired knowledge in order better than before to preserve our lands in a state of suitable fertility. Suppose, for example, that clover, let us say, has been sown with any cereal and that it is left to grow freely, after the harvest; this clover will take a certain quantity of nitrogen from the air, by the help of the nodules on its roots. If this clover is plowed under before the next time of sowing, in the spring or autumn, so as to serve as a green fertilizer, we shall have obtained, with no other expense than the price of the seed, a manure derived wholly from the air of the atmosphere.

This practice, first recommended by Ville, has been recently shown by Deherain to have another advantage quite as important. By keeping the surface of the soil in a state of constant evaporation the interpolated cultivation of the clover diminishes the drainage to a notable extent; all the nitrates, which then are formed in large quantities and which would be lost if the earth remained uncovered, are held and assimilated, being rendered insoluble by the vegetation, and when plowed under will augment by so much the more the natural reserves of the soil.

This method, whether we consider it as the cultivation of a fallow field or whether we call it "sidération,"[a] as proposed by Ville, affords two advantages of primary importance—it prevents in a great measure the losses due to excessive nitrification of the soil in autumn, and restores to the earth a certain quantity of nitrogen which has passed from a gaseous state to the state of organic matter. I do not think it an exaggeration when I say that the gain from this practice alone is equivalent to a strong artificial manuring of the soil, and it may sometimes even attain a value of many hundred francs per hectare, which will be realized in subsequent crops.

Finally, among other examples of the application of this new knowledge there is a most curious fact which has just been pointed out by Salfeld, in Germany, and which, if proved, will be a further confirmation of the immortal doctrines of Pasteur. After clearing a peat bog situated on the banks of the Ems, on the frontier of Holland, horse beans and vetches were sown. The soil was everywhere enriched with mineral fertilizers, but on one part only of the field a small quantity of good arable earth was spread, in the proportion of about 40 kilograms to the are.[b]

The effect of the addition of this latter element was, as it appears, most surprising; under its influence the crop was doubled. This result is, in Salfeld's opinion, similar to the results obtained by Hellriegel and Wilfarth in their laboratory experiments; if this is really so—and it is possible—there will be in the near future a new era, a sort of revolution, so to speak, in practical agriculture.

Perhaps the time is not far distant when our farmers will add to the fertilizers of commerce [the so-called soil improvers and complete manures, etc.—C. A.] true culture broths, prepared according to the methods in use in microbic researches, and which will furnish to plants the germs of organisms capable of fixing nitrogen [the nitrogen fixers], or, perhaps, others still, favorable also to their develop-

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[a] This medical term for atrophy or mortification does not seem quite appropriate in this case.—C. A.

[b] The are is about 119 square yards, or 100 square meters, or 1,071 square feet.

ment and which will cause their crops continually to increase and will finally enrich the soil to the extreme limit of its possible fertility.

This would undoubtedly be a vast extension of that admirable humanitarian work for which we are indebted to Pasteur; but this is anticipation, and I only proposed in this lecture to point out the present state of the question. I shall therefore close by summing up what I have said in a few words.

Experiments made by Ville, and repeated and verified by many other observers, have shown us that certain plants, particularly those of the species of the Leguminosæ, have taken from the atmosphere a part of the nitrogen that they contain.

Berthelot, and also Gautier and Drouin, have shown that the soil alone can to a slight extent enrich itself by means also of a direct fixation of gaseous nitrogen.

Berthelot has also shown that this phenomenon corresponds with the development of certain microbes preexisting in the soil; and, finally, Hellriegel and Wilfarth have discovered this micro-organism in the nodules on the roots of the Leguminosæ.

This last work is certainly one of the greatest interest, and does the greatest honor to the physiologists who have succeeded in bringing it to a final result; but it is proper to recognize that the route to be followed had already been marked out by previous researches. The problem was ripe for solution, and it was in our own country—in France—that the great problem of the assimilation of nitrogen had been proposed and in a great part solved, which is no more than was to be expected from so great a center of production and agricultural progress.

Professor Frank, of the agricultural institute in Berlin, finds that the tubercles may be removed from the plant without stopping the process of taking nitrogen from the air. Evidently, therefore, the subject has to be investigated still further. (Agr. Sci., Vol. IV, p. 68.)

Frank has also shown that the symbiosis in the tubercles of the Leguminosæ is of an entirely different character from that which occurs in the roots of any other plants. Furthermore, when the soil is rich in humus the microbic parasite does no special service to the host, but when the supply of humus is insufficient the microbe symbiont is of the greatest service to the host. (Agr. Sci., Vol. IV, p. 266.)

H. J. Wheeler, of the Rhode Island Experiment Station, gives (Agr. Sci., Vol. IV, p. 55) an account of the work done by Professor Hellriegel at Bernburg, Germany, along the line of investigation conducted by Boussingault and Ville in France, Lawes and Gilbert in England, and W. O. Atwater, of the Storrs School Agricultural Experiment Station. In the present state of the question it may be considered as settled that certain plants are able, if supplied with all the other essential elements, to draw their supply of nitrogen from

the air, either directly or indirectly, by means of minute organisms now generally termed microbes. These microbes can be communicated by direct inoculation from one plant to another that has been previously free from them. Experiments are in progress as to the possibility of cultivating these microbes artificially, and when this has been accomplished successfully it will mark a great step toward the solution of the question as to the plant's method of obtaining nitrogen, and not only that, but a great step toward success in agriculture, since every one will be able to inoculate his own plants, and thus immensely stimulate the yield of crops.

T. Leone has shown that a great number of germs obtain their nitrogen more easily by decomposing the nitrates, and only when these salts are used up do they begin to nitrify the ammoniacal compounds, and after that possibly attack the free nitrogen of the air. He has also shown that these take the nitrogen as a gas from the nitric acid in the nitrates and do not convert it into ammonia. (Agr. Sci., Vol. V, p. 82.)

Leone also shows that the phenomena of nitrification and denitrification occur alternately according to the relative amount of nutriment and number of bacteria present in the water. The manuring of soil, therefore, gives rise to a cycle of phenomena, nitrification being first arrested and the nitrates and nitrites reduced until a maximum formation of ammonia is attained, when nitrification again commences. The destruction of the nitrates and nitrites in the soil is complete or partial according as the supply of manure is abundant or otherwise. (Agr. Sci., Vol. V, p. 107.)

The experiments made in Europe by Boussingault, Hellriegel, and others as to the method by which plants obtain the nitrogen from the atmosphere have been repeated and extended by C. D. Woods, of the Storrs School Agricultural Experiment Station. His results are summarized as follows:

(1) Peas, alfalfa, serradella, lupine, probably clover, and apparently all leguminous plants, have the power of acquiring large quantities of nitrogen directly from the air during their growth. There is no doubt that the free nitrogen of the air is thus acquired by these plants. This acquisition has something to do with the tubercles on the roots of these plants, but the details of the process are still to be solved. The cereals, oats, etc., with which experiments have been brought to completion, do not have this power of acquiring nitrogen from the air, nor do they have such tubercles as are formed on the roots of the legumes. They get their nitrogen from the nitrates or nitrogenous fertilizers. The tubercles on the roots of the legumes may be formed either after or entirely without the addition of solutions or infusions containing micro-organisms, and a plausible supposition is that when such infusions are not furnished the spores of the organisms were

floating in the air and were deposited in the pots in which the plants grew. As a rule, the greater the abundance of tubercles the more vigorous were the plants and the greater the gain in nitrogen. The gain of nitrogen from the air by the legumes explains why they act as renovating crops. (Agr. Sci., Vol. IV, p. 22.)

From some careful experiments by A. Petermann on yellow lupins (*Lupinus luteus*) the author concludes that the physiological rôle of the tubercles must not be exaggerated. They can not be the only cause of the fixation of nitrogen, although their presence may explain why the intervention of atmospheric nitrogen is most marked in the case of the Leguminosæ. He further shows that sodium nitrate is not injurious, but beneficial, to lupins. The trouble in its use results mostly from the fact that it is very soluble and is soon washed down by the rain out of the reach of the roots, which must then draw their nitrogen from the atmosphere by means of the microbic organisms. (Agr. Sci., Vol. IV, p. 264.)

Pagnoul has measured the loss and gain of nitrogen by the soil as the result of the cultivation of special crops. He sowed grass and clover in four pots, but left two others without any crop. The gain of nitrogen permanently fixed in the soil in one year—March, 1888, to March, 1889—was as follows: With no crop the soil gained at the rate of 29 kilograms per hectare per year, with the grass crop 394 kilograms, and with the clover crop 904 kilograms. On the other hand, the total proportion of nitrogen removed from the soil by the drainage water was in each case as follows: No crop, 85; grass, 5; clover, 18. (Agr. Sci., Vol. IV, p. 325.)

Chapter IX.

RELATIONS OF CROPS TO MANURES, FERTILIZERS, AND ROTATION.

The preceding section having shown how easily all the valuable nitrates are dissolved and washed away by rain and how completely the permanent fertility of a field depends upon microbic action within the soil, and especially when attached to leguminous plants, we shall therefore not be surprised to learn that expensive and artificial chemical fertilizers and guanos are often less important than the enrichment that comes more naturally by the rotation of crops.

ARTIFICIAL FERTILIZERS AND MANURES.

As the result of twelve years' experience, J. W. Sanborn, of Missouri, states that although both science and practice assert the efficacy of artificial fertilizers, yet their *profitable use* is a matter of grave concern both in the granite soil of New England and in the richer soil of the Mississippi Valley. His general conclusions are that we do not need to use as much nitrogen in this climate as in Europe, especially as in England, nor as much as has generally been considered necessary; that enriching by rotation of crops is the preferable method; that nitrogen (viz, fertilizers) may be profitably bought only for a few winter or early and narrow-leaved plants, but, as a general truth, broad-leaved plants and those maturing in late summer and in the fall do not require addition of nitrogen to the soil. (Agr. Sci., Vol. I. p. 227.)

From the extensive experiments with fertilizers made at the Ohio Agricultural Experiment Station the following results have been secured, based on both station work and that done by cooperating farmers throughout the State:

Maize.—On soils capable of producing 50 bushels of shelled corn to the acre *no* artificial fertilizer is likely to produce an increase of crop sufficient to pay the cost. On soils deficient in fertility, phosphoric acid may be used with profit.

Wheat.—As a rule no more wheat has been harvested from plats treated with commercial fertilizers than from those receiving no fertilizers, whereas farm manures produced a marked increase. At the present prices of grain and fertilizers the increase of crops will not cover the cost of the fertilizer.

Oats.—Plats receiving nitrates showed a marked superiority in the growing season, but lodged badly before harvest. Muriate of potash gave an insignificant increase. (Agr. Sci., Vol. IV, p. 237.)

E. F. Ladd, of the Agriculture Experiment Station at Geneva, N. Y., urges the necessity of a more thorough and systematic study of climate and soil (Agr. Sci., Vol. IV., p. 36) in order that we may better understand the great diversity and contradictions in the experimental field work, so called. Thus one year's experiments at the same station and with all possible care will show that the "Welcome" oats are vastly more productive than the "White Russian," and the very next year reverses this decision. In the same year a neighboring experiment station operating on the same varieties arrives at opposite conclusions. In 1887 the observations showed that fertilizers did not affect the chemical composition of the grasses, but in 1888 the influence was very marked. Ladd finds that the contradictions in the reports of oat crops for 1885 and 1886 at the Ohio and New York stations are apparently due to considering only such factors as monthly rainfall and temperatures. He urges that the soil temperatures, sunshine, wind, the humidity in the soil, and the aeration of the soil are equally important factors. Any season will give some sort of a crop, but the maximum crop must depend upon the fertilizer and the relation of the fertilizer to the season. Thus Warington has shown that a dry and warm season is most favorable for the action of nitrate of soda, while a moderately wet season is most favorable for the action of sulphate of ammonia. The reason of this appears to be that plants are unable to appropriate to their use the sulphate of ammonia until the salt has become nitrified, and this phenomenon of nitrification does not take place except under the influence of a certain amount of moisture in the soil. A soil that conserves its moisture for a considerable time and is properly cultivated to permit the free permeation of the air gives the best results with sulphate of ammonia, but does not necessarily give the best results with the nitrate of soda, since this is so soluble as to be soon drained away out of reach of the plants. Thus in different seasons, with different fertilizers, we have the crops of wheat shown in the following table:

	Hectoliters per hectare.
Nitrate of soda and a wet season (1882)	23.45
Nitrate of soda and a dry warm season (1887)	31.57
Sulphate of ammonia, wet season (1882)	28.86
Sulphate of ammonia, warm dry season (1887)	23.56

Again, crops, like animals, have a certain limit to their capabilities; if the maximum yield is 50 bushels per acre, then it is a waste to put on more fertilizer than needed to attain this limit. Evidently, therefore, we have to study the relation of the climate to the fertilizers and the soil in order to ascertain a very important item in the relation between climates and crops.

Many specific results as to the relation between climates and crops on a large scale are entirely altered from season to season by the chemical influence of the climate on the fertilizer and the soil in general. We have here, therefore, a source of discrepancy that has contributed appreciably to obscure the influence of the climate on the plant.

PRIZE CROPS.

Evidently crops of seed or grain depend, primarily, on the amount of nitrogen in the sap, and, secondarily, on the elaboration of those precious nitrates into albuminoids. Hence the recognized need of manures, fertilizers, and leguminous crops. But the study of the remarkable crops of corn raised as so-called prize crops in 1889 demonstrates that excellent results may be obtained on some soils without manures, and is otherwise very instructive, since the heavy manuring in many cases must have been largely counteracted by the waste caused by rain. I condense the following from the monthly reports of the department of agriculture of South Carolina for March, 1890, pp. 233–243:

In 1889 the American Agriculturist offered a prize of $500 for the largest crop of corn that should be grown on 1 measured acre of ground during the year 1889. Forty-five leading competitors appeared, of whom 10 were from South Carolina. The average of these 10 prize crops from that State gave 105 bushels per acre, whereas the average of the 25 crops from other States was 103.5 bushels per acre. The accompanying table gives most of the more appropriate statistics for the 7 best results in this list of 45:

Data relative to the best 7 of the 45 competing crops.

Serial No.	Locality.	Soil.	Quantity of fertilizer.
1	Z. J. Drake, Marlboro County, S. C.	Poor sandy soil..	(a)
2	Alfred Rose, Yates County, N. Y.	Sandy loam......	800 pounds Mapes corn manure.
3	George Gartner, Pawnee County, Nebr.	Rich black loam.	90 loads barnyard manure.
4	J. Snelling, Barnwell County, S. C.	Sandy loam......	300 bushels stable manure; 300 bushels cotton seed.
5	L. Peck, Rockdale County, Ga..	......do	4 loads stable manure; 30 bushels heated cotton seed; 1,000 pounds Packard standard fertilizer; 500 pounds cotton-seed meal.
6	B. Gedney, Westchester County, N. Y.	Clay loam	800 pounds Mapes corn manure.
7	E. P. Kellenberger, Madison County, Ill.	Sandy loam......	No fertilizer at all.

[a] *Prize crop No. 1.*—The sandy soil had been fertilized in 1887 by Mr. Drake and had yielded in 1888 the great crop of 917 pounds to the acre of lint cotton, and was therefore already profiting by the heavy enrichment that is had received that year. In February, 1889, in preparation for the present contest, Mr. Drake began a new course of manuring, and from that date until June 11 the following material was added to the soil: One thousand bushels stable manure; 867 pounds of German kainit; 867 pounds of cotton-seed meal; 200 pounds of acid phosphate; 1,066 pounds of manipulated guano; 200 pounds of animal bone; 400 pounds nitrate of soda; 600 bushels of whole cotton seed. The total cost of this manure was $220 and the work in applying it, together with the frequent culture that was given, made the whole expense of the crop $264. The value of the corn that was raised was $206, and the value of the manure left in the soil for the next year's crop was at least $150.

Data relative to the best 7 of the 45 competing crops—Continued.

Serial No.	Variety of seed.	Average distance of hill.	Statistics of harvested crops. Green weight. Cobs.	Green weight. Kernels.	Dry weight. Cobs.	Dry weight. Kernels.	Bushels of kernels. Green.	Bushels of kernels. Crib cured.	Bushels of kernels. Chemically dry.	Water
		Ft. In.								*P. ct.*
1	Gourd variety of southern white Dent improved by 20 years of careful selection on his plantation.	4.0× 6.0	3,133	14,273	2,726	12,132	255	239	217	14
2	Early Mastodon	3.0×12.0	4,134	11,764	2,954	9,764	213	191	174	20
3	do	3.0×36.0	1,821	9,559	1,174	7,647	171	151	137	22
4	White Gourd	4.0×12.0	1,393	7,316	1,212	6,218	131	122	111	15
5	Large White	5.5×48.0	1,826	7,305	1,367	6,136	130	121	110	18
6	King Philip	3.5× 3.0	1,776	6,683	1,154	5,717	119	112	102	19
7	Eclipse variety early yellow Dent.	6.0×30.0	1,497	7,311	617	5,349	130	105	95	31

With regard to the weather and other items during this season of 1889 at these seven stations I have found only the following notes referring to the prize crop No. 1:

Cultivation.—The seed was planted March 2, 5 or 6 kernels to each foot of a row; the plants began to sprout on the 16th; there was a good stand the 25th, and the stalks were thinned out to 1 every 5 or 6 inches on April 8; no hilling was done, but the whole acre was kept perfectly level. The crop was harvested November 25.

Weather.—In March the weather was warm and land moist. Good rains on March 3, 10, and 15; rain on 24th; 1 inch of rain on May 26; 6 inches of rain May 30; rain on June 4 and 5; rain on June 9. The season in general was rainy and wet as compared with other years; rains following frequently, and no irrigation was necessary.

The record of largest corn crop up to this date had been that of Doctor Parker, Columbia, S. C., in 1857, who raised 200 bushels to the acre.

The exact measures of all these 45 competing crops have been made the basis of a comparison showing that on the average of the 17 eastern crops the percentage of nitrogenous matter was 10.78, but for 14 southern crops it was 10.33, and for 14 western crops 10.26, showing an imperceptible difference slightly in favor of the eastern climate and soil and seeds.

In respect to the general advantage of fertilizers, and notwithstanding the apparent advantages gained by some of the heavy manuring in these competing crops, attention is called to the fact that competitor No. 7 raised a very fine crop of 130 bushels green or 95 dry bushels to the acre without any fertilizer whatever, and that the crops reported by Nos. 4, 5, and 6 were even less than his in their

green weight, although larger in their dry weight, after what would ordinarily be called very heavy manuring. These facts are quite in accord with the general results of work at experimental farms, which, according to the South Carolina department of agriculture, have shown that increasing the amounts of the fertilizers beyond a certain point gives no corresponding increase in the amount of grain, and but few of the applications pay for their cost. There is abundant experimental proof that for any given soil there is a limit to the amount of profitable manuring. The process of improving the soil, like the process of fattening cattle, is comparatively gradual and requires time. The margin of profit in the application of manures is narrower than is generally supposed. It is equally important to attend to the selection of the seed, the thorough cultivation, and the natural fertilization that results from the cultivation of the Leguminosæ and the rotation of crops.

PART II.—EXPERIENCE IN OPEN AIR OR NATURAL CLIMATE.

Chapter X.

STUDIES IN PHENOLOGY.

Under the general heading we shall consider, first, the wild plants and their natural habits; second, the plants cultivated at experiment stations under instructive experimental conditions, and, third, the statistics of each and the experience of farmers in general from a practical point of view. The study of the forest or natural habits of plants leads us into the phenology of plant life.

Phenology is a term first applied by Ch. Morren to that branch of science which studies the periodic phenomena in the vegetable and animal world in so far as they depend upon the climate of any locality. Among the prominent students of this subject, one of the most minute observers was Karl Fritsch, of Austria, who in his Instructions (1859) gives some account of the literature of similar works up to that date. He distinguishes the following epochs in the lives of plants, and especially recommends the observation of perennial or forest trees that have remained undisturbed for at least several years. His epochs are:

(1) The first flower.

(2) The first ripe fruit.

The next important are, for the annuals:

(3) The date of sowing.

(4) The date of first visible sprouting.

In order to assure greater precision he adds:

(5) The first formation of spikes or ears.

As Fritsch considers that the development of the plant so far as its vegetative process is concerned depends principally upon temperature and moisture, but that its reproductive process depends principally upon the influence of direct sunlight, therefore he adds a sixth epoch for trees and shrubs—viz:

(6) The first unfolding of the leaf or the leaf bud or frondescence.

This is the epoch when by the swelling of the buds a bright zone is recognized which opens out and the green leaf issues forth. Cor-

responding with the formation of the leaf is its ripening and fall from the tree, which Fritsch adds to his list of epochs, viz:

(7) The fall of the leaf or the time when the tree has shed fully one-half of its leaves; as the wind and heavy rains accelerate this process the date is liable to considerable uncertainty independent of the vitality of the plant. Therefore, in this, as in all other epochs, Fritsch, in endeavoring to lay the foundations of the study, rejected those cases in which any unusual phenomenon, such as wind or drought or insects, had a decided influence on the observed dates.

Many plants blossom a second time in the autumn, although they may not ripen their fruits; therefore in special cases Fritsch adds an eighth epoch, viz:

(8) The second date of flowering. Of course it is understood that if the second flowering is brought about artificially, as by irrigation, pruning, or mowing, that fact must be mentioned.

When the flowers blossom in clusters, such that the individuals are lost sight of in the general effect, then, in addition to the first flower, we note the following item:

(9) The general flowering or the time when the flowers are most uniformly distributed over the plant.

For 118 varieties Fritsch gives in detail the phenomena that characterize the date of the ripening of the fruit. He also gives an equally elaborate system of observations on birds, mammals, fishes, reptiles, and insects, and especially the mollusks or garden snails and slugs.

THE RELATION OF TEMPERATURE AND SUNSHINE TO THE DEVELOPMENT OF PLANTS—THERMOMETRIC AND ACTINOMETRIC CONSTANTS.

Reaumur was the first to make an exact comparison of the different quantities of heat required to bring a plant up to the given stage of maturity, and since then many authors have written on this subject.

I will here give a brief summary of views that have been held by prominent authorities as to the proper method of ascertaining and stating the relation between temperature and the development of plants.

Reaumur (1735) adopted simply the sum of the mean daily temperatures of the air as recorded by a thermometer in the shade and counting from any given phenological epoch to any other epoch. He employed the average of the daily maximum and minimum as a sufficiently close approximation to the average daily temperatures, and evidently in the absence of hourly observations any of the recognized combinations of observations may be used for this purpose. Reaumur found from his observations that the sum of these daily temperatures was approximately constant for the period of development of any plant from year to year; hence this constant sum is called a thermal constant in phenology. For the three growing

months—April, May, and June, 1734—the sum of the daily temperatures for ninety-one days was equivalent to 1,160° C., but for 1735 it was 1,015° C., whence he concluded that the ripening of the vegetation would be retarded in 1735 as compared with the preceding year.

This idea had been familiar to Reaumur for some time previously, and in 1735, as cited by Gasparin, Met. Agric., Vol. II, 1st ed., Paris, 1844, he says:

> It would be interesting to continue such comparisons between the temperature and the epoch of ripening and to push the study even further, comparing the sum of the degrees of heat for one year with the similar sums of temperatures for many other years; it would be interesting to make comparisons of the sums that are effective during any given year in warm countries with the effective sums in cold and temperate climates, or to compare among themselves the sums for the same months in different countries.

Again, Reaumur says:

> The same grain is harvested in very different climates. It would be interesting to make a comparison of the sum of the temperatures for the months during which the cereals accomplish the greater part of their growth and arrive at a perfect maturity both in warm countries like Spain and Africa, in temperate countries like France, and in cold countries like those of the extreme north.

This passage, says Gasparin, is the germ of all the works which have been executed since that time in order to determine the total quantity of heat necessary to the ripening of the different plants that have been cultivated by man.

Adanson (1750) disregarded all temperatures below 0° C., and took only the sums of the positive temperatures. He expressed the law as follows: The development of the bud is determined by the sum of the daily mean temperatures since the beginning of the year.

Humboldt early insisted upon the necessity of taking the sunlight itself as such into consideration in studying the laws of plant life.

Boussingault (1837), in his Rural Economy, introduces the idea of time by adopting the principle that the duration of any vegetating period multiplied by the mean temperature of the air during that period gives a constant product. He takes the sum of the temperatures from the time when vegetation begins and finds the length of the period of vegetation from germination up to any phase, to vary from year to year, inversely as the total sums of the daily temperatures.

Thus, for winter wheat to ripen, he found that there was necessary a sum total of from 1,900° to 2,000° C. of mean daily air temperatures in the shade, which constant sum is equivalent to saying that the average temperature of the growing period is found by dividing this number by the number of days. This method of computation takes

no account of any temperature at which the growth of wheat ceases. A lower limit for such temperature has been adopted by several investigators, such as the 0° C., already mentioned as adopted by Adanson. An upper limit has not yet been ascertained. Edwards and Colin put it at 22° C.; but in Venezuela Codazzi found wheat to mature under a constant temperature of 23° or 24° C. throughout the whole period of vegetation, and, as we shall see hereafter, the upper limit undoubtedly depends upon the humidity of the air, the moisture of the soil, and the total radiation from the sun quite as much as upon temperature. Similarly Marié-Davy calls attention to the fact that maize grows poorly at Paris, where it is cloudy and warm, but well in Alsace, where it is dry and clear, the temperature of the air averaging about the same in both, the difference being in the quantity of sunshine and rain.

Gasparin (1844) adopted the mean temperature of the day as derived from observations made at any convenient hours and took the sum of such temperatures from and after the date at which the plants, especially the cereals, begin to actively develop, or to vegetate, or when the sap flows readily throughout the day. For this "effective temperature" he adopts 5° C.

Subsequently Gasparin adopted a thermometer placed in full sunshine on the sod as giving a temperature more appropriate to plant studies, but still retaining the lower limit of 5° C. for the mean daily temperature of the initial date. Thus he obtained for wheat a sum total of 2,450° C. as the sum of the effective daily temperatures from sowing to maturity.

Gasparin also observed the temperature of a blackened metallic disk in the sunshine and the temperature of the sunny side of a vertical wall, and again the temperature of a thermometer at the surface of a sandy, horizontal soil, all in full sunshine. He recognized that the loss of heat by evaporation must keep the temperature of the soil slightly lower than that of the surface of the wall; but, in default of better methods, he kept a record of the temperature of the wall for many years. From his average results I give the following abstract:

Observations by Gasparin at 2 p. m. daily.

Locality.	Year.	January.		August.	
		Air.	Wall.	Air.	Wall.
Orange	1836-1850	6.7	15.4	30.2	44.1
Paris	1838-1850	4.0	6.3	23.6	30.2
Peissenberg (Munich)	1786	−1.3	11.0	14.6	22.0

The warmth in the sunshine is to the warmth of the air in the shade as though one had been transported in latitude from 3 to 6 degrees farther south.

Another study into the total radiation received by the plants in sunshine was made by Gasparin by placing a thermometer in the center of a globe 1 decimeter in diameter, made of thin copper and covered with a layer of lampblack. Having found by comparison that bulbs of different sizes gave different temperatures, he recommends this size to all meteorologists; but I do not know of observations made by others until Violle (1879) urged the same construction and size for his conjugate bulbs. This bulb in the full sunshine and at a standard distance above the ground seemed, to Gasparin, to give what he calls the temperature of a dry opaque body. The difference between this and the temperature of the air gave a surplus showing the effect of solar radiation on the leaves; again, the difference between this dry, black bulb and the temperature of the surface of the moist earth gave him some idea of the nature and amount of the influence of the sunshine on the surface of the soil, which he illustrates by the following table, derived from seventeen years of observations:

Temperature at 2 p. m.

Month.	Soil.	Black bulb in the air.	Month.	Soil.	Black bulb in the air.
January	6.7	15.4	August	43.1	44.1
February	12.7	22.0	September	31.4	38.9
March	19.1	28.5	October	20.2	28.7
April	25.5	29.4	November	12.1	19.4
May	27.6	34.4	December	5.9	15.4
June	40.9	39.4	Average	24.4	29.6
July	45.3	43.4			

On this table Gasparin remarks:

We see how much the difference of temperatures of the stems and the roots ought to modify the flow of the sap, and there is here an interesting subject for physiological study which should redound to the profit of agriculture. The solar heat contributes also in a remarkable manner to cause the differences in the vegtation of the mountains and the plains. On mountain tops it is the heat of the surface soil and the roots in the sunshine and the effect of sunshine on the leaves that makes possible the existence of a great variety of phænogams. The direct action of the solar heat is the explanation of the possibility of raising cereals and other southern crops in high northern latitudes.

Gasparin (1852, p. 100) gave the following table, compiled for western Europe, showing the mean temperatures of the day during which the respective plants leaf out, flower, or ripen. This early effort to apply meteorological data to the study of plants takes no account, as the author himself says, of other meteorological conditions than temperature such as introduce considerable variations into the phænological phenomena, but he gives it in hopes of helping thus to fix the rela-

tions of natural vegetation to cultivated plants. If in addition to recording temperature, rainfall, sunshine, and other meteorological elements, we could keep a parallel record of the stages of development of cultivated and uncultivated plants we could use the latter as an index to the effect of the weather during any season and predict from that the behavior of the cultivated plants.

Temperatures at the respective phænological epochs for plants in European climates (by Gasparin).

(1) LEAFING.

	°C.
Wild honeysuckle (*Lonicera peryclimenum*)	2.0
Thorny gooseberry (*Ribes uva crispa*)	5.0
Lilac	5.0
Ordinary currant (*Ribes rubra*)	6.0
Broad-leafed willow (*Salix capræa*)	6.0
Horse-chestnut (*Æsculus hippocastanum*)	7.5
Apple tree (*Malus communis*); cherry tree (*Cerasus communis*)	8.0
Fig tree (*Ficus carica*)	8.0
Grapevine shoots	9.5
Mulberry tree covered with leaf-buds; walnut tree	9.8
Sprouting of lucerne grass	10.0
Alder tree	12.0
Oak; mulberry tree developing leaves	12.7
Acacia (*Robinia pseudoacacia*)	13.5

(2) FLOWERING.

Hazelnut tree (*Corylus avellana*); cypress	3.0
Furze or gorse (*Ulex europœus*); box (*Buxus sempervirens*); white poplar (*Populus alba*)	4.0
Broad-leafed willow; honeysuckle	5.0
Peach tree	5.4
Almond tree; apricot tree	6.0
Pear tree	7.0
Elm; apple tree	7.5
Cherry tree; colza	8.0
Lilac; strawberry plant	9.5
Broom (*Genista scoparia*)	10.0
Beans	11.5
Horse-chestnut	12.0
Hawthorn or may (*Mespilus oxycantha*)	12.5
Sainfoin or French grass (*Hedysarum onobrychis*, Leguminosæ)	12.7
Acacia (*Robinia*)	14.0
Rye	14.2
Buckthorn (*Rhamnus paliurus*)	15.0
Oats	16.0
Wheat; barley	16.3
Chestnut tree:	
First flower	16.6
Full flower	17.5
Grapevine:	
Full flower	18.2
Flower passed	19.0
Indian corn; hemp; olive tree	19.0

(3) RIPENING.

	°C.
During increasing heat:	
Fruit of the elm tree	12.0
Green peas	14.2
First cherries; broad beans	16.0
First mowing of sainfoin	17.0
Currants; raspberries; strawberries; cherries	17.8
Morella cherry tree; apricot; plum tree; barley; oats	18.0
Rye	19.0
Peach tree; harvest of corn	20.0
First figs; green gage plums	21.0
First grapes, called madeleine; melons in free earth	22.5
Hemp	22.6
During decreasing heat (for fruits which have received a sufficient quantity of increasing heat):	
Horse-chestnut	18.2
Indian corn; potatoes	17.0
Walnuts and chestnuts	16.2
Pomegranates	15.0
Saffron	13.0
Olives	10.0

NOTE.—It can be easily understood that the fruits which require the greatest prolongation of heat ripen last and are gathered at periods of the lowest temperatures.

Lachmann, in his Entwickelung der Vegetation, counts the sum total of all the temperatures at his station (Braunschweig, Germany) from February 21 onward.

Linsser, for north temperate countries, counts from the date when the temperature 0° C. is attained, but for warmer countries he counts from the date when the lowest temperature of the year is attained; which date would, according to his calculations, be the 8th of February at Braunschweig instead of the 21st of February; but, according to the normal values resulting from the thirty years of observation by Lachmann, this change would only make his sum totals about 10° C. larger.

Tomaschek, as quoted by Fritsch (1866, LXIII, p. 297), takes the mean of all positive temperatures as observed at 6 a. m., 2 p. m., and 10 p. m., omitting the individual negative observations instead of the negative daily averages. He counts the sums from January 1; this method gives figures that agree very closely, at least in Europe, with those given by Fritsch's method.

Kabsch, as quoted by Fritsch, attempted an improvement on the method of Boussingault. His formula is especially appropriate to the annuals, but not to the perennial plants. His method of computing the thermal constant is expressed by Fritsch in the following formula:

$$x = t \pm \left(\frac{h\,t}{12}\right)c - C$$

where the notation is as follows: C is the total heat from the date of sowing up to the date of sprouting; x is the thermal constant from one phase to the next, such as from sprouting to flowering; t is the number of days from sprouting to flowering; c is the mean daily temperature from sprouting to flowering; $t\cdot c$ is the total sum of mean daily temperatures from sprouting to flowering; as this temperature is principally active during the daytime, therefore one-twelfth of $t\ c$ represents the efficient heat during an hour; h is the duration in hours of an average growing day, viz, from sunrise to sunset; therefore one-twelfth of the product $c\ h\ t$ represents the total heat that has been utilized by the plant.

The method of reasoning by which Kabsch arrives at the above formula, which I have quoted from Fritsch, is not known to me.

Sachs, by direct experiment, finds that for each plant there is a temperature most favorable to its growth and two other limits, minimum and maximum, beyond which it will not grow.

Deblanchis finds that the temperature on which vegetation depends is not the ordinary temperature of the air as given by a sheltered thermometer; he prefers to approximate to the temperature of the leaf of the plant by the use of his "vegetation-thermoscope," which is an ordinary minimum thermometer covered with green muslin and kept moist, as in the ordinary wet-bulb thermometer. He places his thermometer at one and a half meters above the soil and in full exposure to sun and sky. Evidently the sum total of his temperatures will be between the sums of the ordinary wet-bulb and the ordinary dry-bulb thermometers, but must differ greatly from the temperature of the roots on which the growth of the plant primarily depends.

Hoffmann prefers to take for the daily temperature the excess above freezing of the maximum thermometer exposed to full sunshine and free air. Hoffmann's temperatures approach more nearly the temperature of the roots within a few inches of the surface of the ground. Besides taking the sums of the average daily temperatures of the shaded air thermometer, omitting all negative values or all those below freezing point, Hoffmann also took the sum of the bright bulb in vacuo and of the black bulb in vacuo, both in full sunshine; these latter temperatures are generally higher than those of the roots and much higher than those of the leaves. Hoffmann prefers to use the readings of the bright bulb in vacuo.

Hervé Mangon (1879) modifies Gasparin's method slightly in that he takes account of the shade temperatures of the air from the date of sowing up to the date of harvest, rejecting all cases where the mean daily temperature in the shade is less than 6° C.; he had been led to think that the vegetation of cereals and other important crops ceases below this temperature. Thus he determines the sum total

needed for ripening the crops of the varieties of wheat ordinarily cultivated in Normandy, as shown in the following table:

Date of sowing.	Date of harvesting.	Sums of daily temperatures.		
		From sowing to Feb. 29.	From Mar. 1 to harvest.	Total.
		° C.	° C.	° C.
Nov. 17, 1869	Aug. 12, 1870	356	2,000	2,356
Nov. 5, 1870	Aug. 20, 1871	359	2,158	2,517
Nov. 27, 1871	Aug. 4, 1872	395	1,914	2,309
Nov. 5, 1872	Aug. 3, 1873	632	1,806	2,438
Nov. 27, 1874	Aug. 10, 1875	339	1,880	2,219
Nov. 4, 1875	Aug. 3, 1876	490	1,828	2,318
Nov. 18, 1876	Aug. 2, 1877	701	1,769	2,470
Dec. 6, 1877	Aug. 7, 1878	367	2,035	2,402
Dec. 21, 1878	Sept. 1, 1879	171	2,085	2,256
Average, Nov. 17	Aug. 8	455	1,924	2,379

By similar calculations Hervé Mangon obtains for other crops as cultivated in Normandy the following results:

	Mean date.		Sums of daily temperatures from sowing to harvest.
	Sowing.	Harvesting.	
			° C.
Oats	Mar. 7	Aug. 5	1,826
Do	Nov. 8	Aug. 20	2,197
Barley	Apr. 13	Aug. 18	1,810
Beans	Mar. 3	Aug. 25	2,210
Buckwheat	June 10	Sept. 10	1,525

Hervé Mangon concludes his essay with two important practical rules, deduced from his data relative to the climate and crops of the department of La Manche: (1) In a mild and uniform climate, like that of the northwest of France, there is always an advantage in sowing the seed early in the autumn; (2) by computing annually the sums of the degrees of temperature observed since the date of sowing and by consulting the numerical tables given in this memoir one can, with great accuracy, calculate four or six weeks in advance the date of the approaching harvests of the respective plants.

The tables given by Mangon for his locality can be reproduced for American stations wherever the meteorological observations and the dates of planting and harvesting are recorded; although it may be possible to consider more minute details of climate and soil than he has done, yet the success attained by him in his elementary collation of fundamental data must stimulate to similar work in this country.

From the data given by Mangon, Marié-Davy deduces some further phenological constants which will be useful, viz, for winter wheat in Normandy, the sum of the daily temperatures in the shade, rejecting all below 6° C., from sowing to germination is 85° C.; from germination to heading, 555° C.; from heading to maturity, 1,810° C. This gives from sowing to heading 640° C., whereas Gasparin, following his own rule, which takes the sum of all temperatures after the date at which the temperature of 5° C. is attained, finds 430° for this constant.

Wheat begins to grow visibly when the mean daily temperature is about 6° C. This mean daily temperature is attained on the average of many years on the dates given in the second column of the following table. (See Marié-Davy, 1881 and 1882, p. 184.) The average dates of harvest are given in the third column; the interval or growing period in the fourth column; the fifth column contains the sums of the mean daily temperatures of the air in the shade (after the date on which a mean temperature of 6° was attained), the sixth column gives the sums of the mean daily temperatures of the thermometer in the full sunshine, as determined by Gasparin. The close agreement of the two latter numbers is considered by Marié-Davy an argument in favor of the idea that temperatures in the sunshine are better than those in the shade as a measure of the influence of heat and light on the growth of plants.

Place.	Date of 6° C.	Wheat harvest.	Growing period.	Sum of shade temperatures.	Sum of sunshine temperatures.
			Days.	° C.	
Orange	Mar. 1	June 25	117	1,601	2,468
Paris	Mar. 15	Aug. 1	138	1,970	2,433
Upsala	Apr. 20	Aug. 20	122	1,545	....
Lyndon	June 15	Aug. 27	72	675	....

Balland (see Marié-Davy, 1881, p. 186) has made a perfectly similar computation with reference to the ripening of wheat cultivated on a large scale at Orleansville, in Algeria, with the following results:

1878	2,498
1879	2,433
Average	2,462

The results of Mangon, Balland, and Gasparin agree so closely that a strong argument seems to be afforded in favor of using the thermometer exposed to the full sunshine. The differences in their results are quite comparable to the differences found by Vilmorin to exist between different varieties of the same seed.

The values of the thermometric constants, as computed by Herve Mangon's method, for other grains cultivated in Normandy are given

in the following table, where the figures represent the sums of sunshine temperatures necessary to complete the growth from germination to harvest.

Plant.	Sunshine temperature.	Plant.	Sunshine temperature.
	° C.		° C.
Algerian wheat	2,462	Normandy barley	1,810
Normandy wheat	2,365	Normandy beans	2,210
Normandy oats	2,197	Normandy buckwheat	1,579

Marié-Davy (1881), in his chapter on the influence of heat on the time required for vegetation, adopts the principle enunciated by Boussingault, of the equality of the sum total of the temperatures, but thinks that the temperature required to bring a plant to the flowering stage is the sum of the mean daily temperatures in the full sunshine, and not the temperature of the air in the shade. According to his view, the heat is needed in the soil in the early part of the growth of the plant; but after the flower is formed, or during the process of perfecting the fruit, sunlight is needed, and during this stage he uses the actinometric degrees of the Arago-Davy actinometer as an index of the progress of the plant. I have, therefore, in the following table collated the figures given by him for wheat. The third column gives the sum total of the mean daily shade temperatures, counted from February 1 of each year up to the date at which the total amounts to 1,264° C., or within half a day thereof, that being the adopted shade constant for the flowering of wheat that was sown on or about the 21st of March. The fourth and fifth columns give the dates and sum totals of temperatures observed with a naked-bulb thermometer on the grass in the full sunshine, assuming 1,569° C. as the thermal constant for this thermometer. The sixth column gives the observed dates of flowering. As these dates agree with those in the fourth column better than with those in the second column, Marié-Davy considers them as confirming him in the use of the unprotected solar thermometer. In order to bring out the total effect of sunlight and sun heat Marié-Davy has computed the sum total of actinometric degrees from February 1 up to the dates given in column 2 and in column 4, respectively. These results are given in columns 7 and 8, which show that 1878 was a very precocious year, as compared with the others, in that the date of flowering was very early, but the sum total of its actinometric degrees was very small and its crops were very poor. 1879 and 1877 show larger actinometric sums, but the largest sums are given by the years 1873, 1874, 1875, and 1876, which were also very excellent crop years.

Date of flowering of wheat at Montrouge, France.

[See Marié-Davy, 1880, pp. 181–215.]

Year.	Shade temperatures.		Sun thermometer.		Observed date of flowering.	Actinometric percentages.	
	Date.	Sum total.	Date.	Sum total.		Shade dates.	Sun dates.
		°C.		°C.			
1879	June 21	1264	June 21	1569	June 21	4063	4063
1878	June 6	1268	June 10	1566	....	3467	3666
1877	June 12	1274	June 15	1578	June 15	3976	4075
1876	June 15	1269	June 19	1567	June 19	4376	4588
1875	June 7	1264	June 13	1574	....	4298	4603
1874	June 10	1277	....	....	June 9	4506	....
1873	June 19	1256	....	....	....	4296	....

Marié-Davy concludes that by keeping a daily summation of actinometric degrees it becomes possible, even at the epoch of flowering of wheat, to estimate in a very approximate manner what will be the final value of the resulting harvest. At this moment, even if we have already measured the sum of the products which should be applicable to the formation of grain, we can not be absolutely cert in that the harvest will correspond to our expectations. A certain time is necessary for the nutrient particles to traverse the various parts of the stem up to the seed, and a certain quantity of water is necessary for this transportation. An excessive dryness or heat will interfere with this movement and will give a poorly developed grain, notwithstanding the abundance of nutrition reserved for it within the plant. But although water and nutrition are as important as heat and light, still we find that predictions based on actinometric degrees alone are very reliable.

According to Georges Coutagne, the law that connects the rate of development of a plant with its temperature must be such that it has a maximum value for a special temperature and diminishes as we depart from this down to a zero rate at the freezing point and also to zero at some higher temperature at present unknown; all this is on the assumption that the sunlight, moisture, and winds are such as to enable the plant to do its very best at the given temperature. If this law were known we could then determine whether a plant would live and flourish in any given climate.

This law of growth has been expressed by Georges Coutagne, as quoted by Marié-Davy (1883, p. 227), by the following notation and formula. Let—

v be the rate of development of the plant, assuming that other conditions are so adjusted that it attains the maximum growth possible for the given temperature;

x be the temperature of the plant;

a be a coefficient that defines the rate of development so that the reciprocal of a defines the longevity of the plant;

n be a coefficient that defines the sensitiveness of the plant to temperature, so that as n increases a given change in x has a less effect on the rate of growth and therefore the plant can flourish in a wider range of temperature; therefore its geographical distribution may be wider, hence Coutagne calls n a coefficient of ubiquity;

c be the temperature at which the most rapid development is possible under the most favorable conditions of growth or the temperature optimum; plants with a large value of c must live nearer the equator than those having small values of c; therefore c is called the index of tropicality.

According to Coutagne these quantities are bound together by the formula:

$$v = a\,e^{-\left(\frac{x-c}{n}\right)^2}$$

This formula represents the momentary rate of development, so that the total duration of the growth is to be found by integrating this expression, which result is written as follows:

$$L = \int_{x_2}^{x_1} a\,e^{-\left(\frac{x-c}{n}\right)^2} dx$$

Van Tieghem, like Coutagne and others, finds that for each special phase of vegetation, germination, heading, flowering, or ripening, and for each age of a perennial plant there exists a special relation between the temperature, the light, the moisture, and the chemical composition of the soil and water that is most favorable to growth. We have, therefore, to decide whether the same formula of development can represent the growth in each of these phases as well as throughout the whole career of the plant. As we have before said, the plant can only rearrange the inorganic products that it receives and develop its own structure by utilizing the molecular energy contained in the sunshine or some equivalent light. Its growth does not depend upon any force contained within the plant nor on the temperature, as such, but on the quality of the radiation; therefore any formula that considers temperature only must be a very imperfect presentation of the growth, especially in those stages subsequent to the full development of the leaf and flower.

Lippincott (1863, p. 506) gives a few items relative to the phenology of wheat in America and the origin of the varieties known as Lambert's Mediterranean China (or Black Tea), Hunter's, Fenton, Piper's, which were all due to judicious selection and careful culture.

The average wheat crop of England is stated to be 36 bushels per acre and that of the United States 15 or less, which large difference is, he thinks, the result of judicious cultivation and care in the choice

of seed rather than the influence of climate, since large crops have been and can be raised in this country.

The injurious influence of hot, moist, and rainy weather has, he thinks, a general tendency to deteriorate the quality of American wheat, as the plant needs a hot and dry climate. Moisture defines the southern limit of wheat cultivation while the northern limit has not yet been found. In 1853 the growing season in England was too cold to ripen, the average being 57° F. for July and 59° F. for August, so that only one-half or one-third of the usual crop of wheat was harvested.

In Bogota, Colombia, where the temperature of the high plains is quite low, wheat that is sown in February is harvested in the last week of July, or in 147 days, at a mean temperature of 58° or 59° F. At Quinchuqui wheat is sown in February and reaped in July at a mean temperature of 57° or 58° F. Hence Lippincott concludes that in general wheat requires a mean temperature of 60° during the last month of its maturity, or a mean temperature of 56° during the whole period of growth.

In England in 1860 wheat sown March 28 ripened August 20. Of these 145 days there were 133 that had temperatures above 42° F. In 1861 130 days were required of temperatures above 42° F.

When the temperature of the soil during the last phase of growth (viz., from earing to maturity) falls below 58° to 60° F. no progress is made in the growth, and unless 60° is exceeded the crop never fairly ripens. These figures appear to accord closely with the requirements of the wheat plant in the United States, where it is found that those regions having a mean temperature for May between 58° and 60° F. can not mature the wheat in May, but those having a June temperature above 61° can ripen the wheat in that month. Those having a temperature of 61° in July can mature spring wheat which is sown the 10th of April or the 10th of May. Those having a mean temperature of 61° in May can mature the winter wheat in that month.

Lippincott gives the following items: At Arnstadt, Germany, wheat requires from flowering to maturity 53 days at a mean temperature of 63° F., or a total of 3,339° F.:

At Richmond, Va., Japan wheat headed April 30, 1860, and was reaped June 14, or 46 days, with a sum total of mean daily temperatures of 3,086° F.:

At Haddonfield, N. J., Mediterranean wheat sown early, headed May 18, 1864, and matured June 30, or 44 days, with a sum total of 3,024° F. of mean daily shade temperatures:

In Monroe County, N. Y., wheat headed May 10, 1859, and matured July 8, or 56 days, with a sum total of 3,562° F.

The preceding meager data are all that Lippincott was able to find

with regard to wheat in America after an extensive research, but within the past few years much more attention has been given to this subject.

The differences between the quantities of heat required in England and America and the differences in the varieties of the wheat were apparent to Lippincott. Thus, he finds that in England the lengths of the periods and the sums of the temperatures were as follows: In 1860 a period of 59 days and a sum of 3,562° F.; in 1861 a period of 50 days and a sum of 3,225° F.; in 1862 a period of 56 days and a sum of 3,406° F. The reduction of the mean temperature during two months of 1853 by merely 2° F. cut off one-third of the crop and brought a famine that was already foreseen in July, 1853. On the other hand, it increased the exportation of wheat and flour from the United States from $14,000,000 in 1852 and $19,000,000 in 1853 to $49,000,000 in 1854.

A careful study of the sum totals of rainfall, temperature, and sunshine should enable one, in general, to foresee similar failures and corresponding successes in the crops of any region.

QUETELET.

The suggestive, but sketchy, studies of earlier writers on thermal constants were supplemented by more elaborate investigations and calculations of statistics by Quetelet (1849) in his Climate of Belgium, from his own summary (p. 62), etc., I take the following notes:

The details hitherto given show sufficiently that the relative conditions of vegetation change at all times of the year in two countries situated at a distance from each other. Acceleration and retardation are quantities essentially variable, and it is erroneous to say that one locality has its budding period ten or twenty days sooner, for example, than another. This difference may be correct for one season of the year and entirely wrong for another; and, moreover, we can only pretend to state a fact which applies to the majority of plants.

Nevertheless the differences in the periods of budding are not so variable but that we can assign to them values very useful to consult in practice. On the other hand, science needs to establish some well-determined facts in order to arrive later at the knowledge of the laws upon which these variations depend. I believe that in the actual state of things I shall be able to settle upon the following epochs, in order not to multiply too much the terms of comparison. Moreover, the numerical tables justify, to a certain extent, the distinctions which I lay down.

Let us first observe that the awakening of the plants is brought about by the cessation of the cold, and it suffices to consult the tables of temperatures for the different countries to determine the average epoch at which many plants will put out their leaves or their flowers. These first indications, which it is well to collect, still do not determine, however, the general movement of vegetation which may

manifest itself more or less slowly. They are given by the budding of the *Galantus nivalis*, of the *Crocus vernus*, by the appearance of the catkins of the *Corylus avellana*, of the leaves of the *Ribes grossularia*, of the *Sambucus nigra*, of the honeysuckle, and of some spireas.

The falling of the leaves is also determined by the temperature, and in our climate generally takes place after the first frosts. This period and that previously mentioned come ordinarily at the two limits of winter, and they separate to make place for the different stages of vegetation in proportion as the cold of winter has a less duration. The winter sleep lasts in our climate from three to four months; in southern countries it is very much shorter. We can even imagine a line on the surface of the globe where it ceases altogether for the generality of plants.[a]

The great movement of vegetation commences in Belgium in the middle of March and terminates at the end of April. I will call this the period of leafing (feuillaison), because during this interval the different plants are covered with their verdure and some of them show their first flowers.

The second period is that of flowering (floraison), which in our climate would include the months of May and June and the first half of July.

The third period would then come, which is that of ripening (fructification).

These three great periods should undoubtedly be in their turn subdivided, but the present state of the observations does not allow of such detail. It is understood, moreover, that the names I have given to them only serve to designate the principal phases of vegetation which take place. Thus, in making the general table [omitted—C. A.] I have classed the different plants according to the following seasons:

Awakening of the plants.—This period is determined by the plants comprised in the [omitted] table.

Leafing.—This period comprises the plants which, in Brussels, put out their leaves from the 15th of March to the 30th of April, and which bud during the same two months.

Flowering.—I have made use of the plants which have flowered or brought forth their fruit from the 1st of May to the 15th of July.

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[a] As I have already observed elsewhere, the awakening is an epoch that is not the same for all plants. I mean to speak here only of the epoch when the sap begins to circulate in the majority of the plants which grow in our climate. "All plants do not begin to vegetate at the same period," says M. Ch. Martins, in the Botanical Expedition along the Northern Coasts of Norway. "Thus in some the sap begins to mount when the thermometer is only a few degrees above zero (centigrade); others need 10 or 12 degrees of heat, while those in warm climates require a temperature of from 15° to 20° C. In a word, every plant has its own thermometric scale, whose zero corresponds with the minimum temperature at which vegetation is possible for it. Consequently, when we wish to determine the sum total of the temperature that has determined the date of flowering (fleuraison) of each of these plants it is logical to only consider for each plant the sum of the degrees of temperature above zero (centigrade), since these temperatures are the only ones that have been efficient in inducing or sustaining their growth." In tropical countries the great fluctuations in the vegetable kingdom are not regulated by the same meteorological elements as are effective with us; there the rainy season produces very nearly the same effects as the cold season does in our climates.

Ripening.—This period comprises the stage of vegetation, which, for Brussels, extends from the 15th of July to the falling of the leaves, the last limit of the period with which we are occupied here.

This classification has allowed me to put into [the omitted] table the observations gathered from other sources, as well as from the system of comparative observations which the Royal Academy of Belgium has succeeded in establishing at Brussels.

The average influence of location on the annual progress of vegetation.

Locality.	Position.			Acceleration or retardation of phases of vegetation relative to Brussels.				
	Longitude from Paris.	Latitude north.	Altitude.	Awakening.	Leafing.	Flowering.	Fruiting.	Fall of leaf.
	m. s.	° ′	*Meters.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*
Naples	47 40 E.	40 52	......	......	+38	......	......	......
Alais	6 57 E.	44 7	143	......	+14	+12	+40	......
Venice	40 4 E.	45 26	11	+20	+ 4	+18	+30	−19
Parma	31 59 E.	44 48	49	+ 2	+ 2	+16	+51	−10
Guastalla	33 15 E.	44 55	......	+14	+ 7	+18	+49	......
Geneva	15 15 E.	46 12	408	......	− 1	− 6	+12	......
Lausanne	17 11 E.	46 31	538	......	− 2	+11	......	......
Carlsruhe	24 17 E.	48 59	380	−11	− 3	+15	......	+11
Dijon	10 48 E.	47 19	240	− 3	− 1	+ 6	+15	+18
Paris	0 0	48 58	37	......	+ 6	+ 5	......	......
Montmorency	0 30 W.	49 0	140	......	− 5	−12	+14	......
Valognes	15 14 W.	49 31	......	+27	0	− 1	+19	......
Polperro, England	......	50 15	......	+41	+10	− 2	......	......
Swaffham, England	......	......	......	+26	− 1	− 4	......	− 4
London	9 45 W.	51 30	30	+32	+ 6	− 7	− 5	......
Makerstoun	19 25 W.	55 35	64	......	+ 2	......	......	......
Liege	12 46 E.	50 39	......	+ 6	0	0	......	......
Louvain	9 26 E.	50 53	......	− 1	− 3	− 2	......	......
Brussels	8 6 E.	50 51	60	0	0	0	0	0
Ghent	5 34 E.	51 3	......	− 3	− 4	+ 1	0	+12
Bruges	3 33 E.	51 13	......	......	− 8	− 8	......	......
Ostend	2 20 E.	51 14	......	− 4	− 8	− 8	− 9	+ 3
Lochem	......	......	......	− 6	−15	− 5	......	− 2
Utrecht	11 8 E.	52 5	......	−15	−18	− 6	−15	− 3
Vught, Holland	......	......	......	−24	−18	+ 4	− 1	+ 3
Joppe, Holland	......	......	......	− 9	−10	−15	......	......
Groningen	16 56 E.	53 13	2	−20	−23	−18	−29	− 2
Munich	37 5 E.	48 9	526	−20	−19	−15	......	......
Prague	48 20 E.	50 5	178	......	−19	− 8	......	+ 7
Tubingen	26 51 E.	48 31	331	......	−22	......	......	......
Berlin	44 14 E.	52 31	36	......	−20	......	......	......
Stettin	48 54 E.	53 25	......	−22	−20	−14	− 6	......
Jevers	22 16 E.	53 34	......	−44	−23	−22	......	......
Gottenborg	38 31 E.	57 42	......	......	−27	......	......	......
Grippenberg	......	57	......	......	−27	......	......	......
Nasinge	......	59	......	......	−27	......	......	......
Carlstadt	44 4 E.	59 23	49	......	−14	......	......	......
Arosia	......	59 46	......	......	−24	......	......	......
Lapland	......	68 30	......	......	−57	......	......	......
United States of America, central New York	......	43	......	......	−30	......	......	......

This table of average intervals shows how variable is the acceleration of one place over another during the different seasons of the year. This acceleration even often changes into retardation, consequently the isanthesic lines are far from remaining parallel. We therefore conclude that latitudes and longitudes are not the only and principal causes which regulate the phenomena that are engaging our attention, because these unchangeable causes could not produce different effects; it is the same with regard to altitudes, we must only consider them as intermediary agents, and we should do wrong to take them as the basis of calculations for determining the epochs of natural phenomena.[a] Let us see whether temperatures will give more satisfactory results. In order to facilitate the comparison I have gathered in the table (which unfortunately has not been completed for all the localities)[b] the average temperatures for years, seasons, and months.[c] I must limit myself to consulting these elements, as I have not the necessary data to compute the base of daily temperatures and particularly to take the action of the sun into consideration. This first work will perhaps make us feel the incompleteness of the system of meteorological observations adopted at present (1849) in Europe. I have also been obliged to exclude the influence of the temperature of the earth, although it is absolutely necessary to consider it, in order to treat the phenomena of vegetation in a complete manner.[d]

The mean temperature in winter at Brussels is 2° C. The most favored localities in comparison with it are Naples, Alais, and Polperro (near Lands End, England). I have not been able to deter-

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[a] It will be understood that I wish here to speak only of the action of geographical circumstances considered outside of the influence of temperature. This action has been but little studied up to the present time, but it is well worthy of our consideration. The following is what one of the most distinguished living botanists of the present time has written to me on this subject: "The distribution and extension of each species of plant over the earth shows us that the plants in general and each species as a unit are subject to organic changes dependent upon longitude and latitude. Each has a limited range; between these boundaries it has its paradise, where it thrives best. The organic changes which take place in individual plants, if one compares those that are native in different places, are such that we might presume that even their periodic phenomena must be affected. For example, all plants are stunted in height and in the number of their leaves toward their northern limit (or rather polar limit). They change their general appearance in going from east to west on the same parallel; they alter as to the extent of inflorescence and the size of flowers in going north or south on the same meridian. Now, as it is only by means of these organs that the plant vegetates in the presence of the world outside of it, it is necessary in our observations to begin with the relation of those organs, or rather the consideration of the developed organs ought to enter into our notation of their vital action. It further follows from this that we ought to study plants whose natural boundaries are known to us; these are the true barometers for vegetable life" [i. e., as the barometer is the measure of the activity of the atmospheric forces, so the natural geographic boundaries are the measures of the vital activity of plant life]. (Letter of M. de Martin's Observation of periodic phenomena, "Mem. Acad. Royal," Brussels, Vol. XVI, p. 11.)

[b] Further, it has sometimes been necessary to give the temperature of a neighboring locality instead of that of the place itself; thus for the temperature of Polperro I have taken that of Penzance, and the temperature of Makerstoun has been replaced by that of Edinburgh, etc.

[c] I have omitted these figures in my copy of Quetelet's table.—C. A.

[d] I should have liked to supplement this work with maps showing the principal epochs in vegetation, but the collected observations are not yet sufficiently

mine the epoch of the awakening of the plants in the first two places, but in the last mentioned the acceleration is forty-one days. This acceleration is also very great at the other stations of England, as well as at Valogne, which has also probably a sea temperature.

It has also been impossible for me to fix the time of awakening for places where the winter is the most rigorous, such as Lapland, Sweden, and the United States. We have seen, however, that there is twenty days retardation in places where the mean temperature is very little below zero. Jever seems to be an exception to this rule; but the results obtained in this place were only deduced from three observations.

The epoch of leafing corresponds, as we have said, with the end of March and the month of April, and that of the flowering with the months of May and June. The first includes the commencement of spring, the other the end of it. Thus the temperature of Brussels in spring is 10° C. The greatest variations besides are at Naples and at Alais. It is also in these places that the leafing takes place first. Venice, Parma, and Guastala are very little in advance, but the month of March and the beginning of April are scarcely any warmer than at Brussels. The difference of temperature is only felt in a marked manner in the following months. The flowering also takes place about eighteen days sooner.

Polperro, in regard to leafing, is about ten days in advance. The temperature in March is much higher than that of Brussels, while in April it is about the same. The advantage is lost in the following months, when, as regards flowering, Brussels is in advance of Polperro, as well as of the localities in England.

Brussels is about eighteen to twenty days ahead of the towns of Holland and Germany in the epoch of leafing, and is behind in the

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complete to allow of undertaking such a task. The first chart would have shown by a series of lines drawn over Europe the awakening of plants for each ten days, that is to say, a first line would indicate the localities where the awakening first takes place immediately after the coldest day of the year, which with us is about the 20th of January; a second line would pass through places where the awakening is on an average ten days later, and so on. Another system of similar lines traced upon a second chart would have indicated in the same way the beginning of budding, always proceeding by intervals of ten days. We should also have made similar charts for flowering and ripening and the fall of the leaves. By comparing these charts we should be able to see at a glance the principal changes which take place in these various systems of lines. In order to complete this study we should imagine other systems of lines relating to temperatures. Thus one system would show the localities in Europe where frosts first cease, always advancing at intervals of ten days; then another system for places which, at successive intervals of ten days, and beginning from the awakening of the plants, have reached a sum total of temperatures amounting to 183° C., corresponding to the epoch of leafing; further, a third system of lines which should pass through places that, counting from the time of awakening, have successively attained the total number of degrees of temperature necessary for the flowering of plants; and so on for further systems.

The charts relating to vegetation and those relative to temperatures would, by comparing them, give much curious information. Unfortunately the observations we possess of daily temperatures are still as rare as those of the flowering. I have therefore been compelled to renounce that portion of my work.

flowering season, particularly as regards Prague, where the temperature in April, May, and June is a little higher than that of Brussels.

The retardation for stations in Sweden, the United States, and Lapland is sufficiently explained by an examination of the temperature tables, and also in regard to the epoch of ripening (fructification).

I have already had occasion to call attention elsewhere to the fact that the falling of the leaves (effeuillaison) depends less upon the temperature of the year than upon the effects of the first cold. Thus the leaves fall sooner in the north than in the south, unless they fall sooner here on account of a season of great dryness or excessive heat.

It would be superfluous to consider the influence of the other meteorological agents when we still possess so little information as to the mode of action of the principal cause, which, in our climate, dominates in some degree all the phenomena of vegetation.

The temperature month by month at Geneva and Lausanne vary little from that observed at Brussels. The winter months there are a little colder and the vegetation is a little behind. Toward the time of ripening this retardation changes into an advance. The temperature, however, in spring and winter is no higher than that of Brussels.

Is not this advantage to be attributed to the fact that Geneva and Lausanne, having a higher elevation, enjoy purer air and a more efficient solar radiation, elements which are not indicated by the thermometer? By following the mode of calculation generally adopted one would say that the difference of latitude between Brussels and the two Swiss cities is compensated by their different altitudes. Geneva and Lausanne are 4° 30′ farther south than Brussels, while their elevation averages about 420 meters greater, which shows that a degree of latitude farther north is about equal to an increase in height of 120 meters. At Munich and Gröningen the same plants flower almost simultaneously, yet their latitudes and elevations are very different. Munich is 5° 4′ farther south, but is 524 meters higher. Here again a degree of south latitude nearly compensates 100 meters of elevation. It is to be regretted that we do not know the annual temperature of Gröningen. Berlin and Stettin seem to approach that locality very nearly in the natural epochs of their plants. Indeed there is very little difference in their latitudes, their elevations, and probably, also, in their temperatures.

Carlsruhe and Brussels have about the same annual temperature. The winter and early spring are a little colder in the first than in the second of these cities, consequently the vegetation is a little later; on the other hand the months of April and May are warmer, therefore, we see the vegetation changes its retardation into an advance.

Carlsruhe is about 2 degeees south of Brussels. For this reason alone vegetation should be about eight days in advance as at Paris; but on the other hand its altitude is about 300 meters greater than that of Brussels, and its vegetation should for this reason be about twelve days later. Combining the effects of these two causes, Carlsruhe would still have a retardation of more than four days, which is confirmed by experience for the first portion of the year; but in the second part we see this retardation change to an advance of fifteen days. Should we not here again remark, as was done before, that,

other things being equal, vegetation is much more active on high plateaus, where the radiation is greater, as well as in localities where the annual variations are very marked? This activity is further reenforced if the locality is near the polar regions, where the light acts almost uninterruptedly when once the awakening of the plants has taken place. In this respect Russia and Lapland present us with notable examples of this reënforcement.

Kupffer, in his "Note relating to the temperature of the soil and of the air at the limits of the region of cultivation of cereals," gives the following temperatures for the three principal boundary points of this region:

	Longitude.	Latitude.	Altitude.	Mean temperature.				
				Year.	Winter.	Spring.	Summer.	Autumn.
	° ′	° ′	Feet.	° C.	° C.	° C.	° C.	° C.
Irkutsk	101 15	52 17	1,300	−0.25	−14.1	−0.2	+12.5	+ 0.8
Nertchinsk	117 1	51 18	2,100	−3.2	−21.7	−1.0	+12.9	−2.9
Archangel				+0.7	−10.0	−0.2	+11.5	+1.5

"A comparison of the curves for Nertchinsk, Irkutsk, and Archangel demonstrates in a striking manner," says Kupffer, "under what climatic conditions the cultivation of cereals can be carried on notwithstanding the lowness of the average annual temperature. All the curves agree together in spring and autumn, whence it results that it is especially the temperature of spring and autumn which influences the cultivation of cereals; it is in these seasons, in fact, that occur the two most important periods of the year for agriculture—the time of sowing and the time of reaping. In the cultivation of rye autumn plays a still more important part, because rye is sowed also in autumn." Kupffer calls attention in another part of his note to the fact that some kinds of farming are carried on where the soil below the surface is frozen. "Experiments in farming," he says, "have been made at Irkutsk, on a very small scale it is true, but which in many respects have been a success. This is due to the fact that the soil becomes soft on the surface and is thus capable of developing the germs received by it; its mean temperature is above zero four months in the year, which is sufficient to ripen the cereals in a country where continuity of the sunshine makes up for the weakness of solar action. Snow often falls upon the sheaves, but still they harvest them." These examples confirm what we have said in regard to annual changes of temperature. In no locality in the world are these variations greater than here; at Yakutsk the difference of temperature between the warmest and the coldest month of the year is 50.9° C.; at Irkutsk, it is 24°.1; at Nertchinsk, 39.°1; at Archangel, 28.2° C.

It might be said, it is true, that the average temperature of the year should not be considered here, not even that of the free air, so long as the plants are covered by snow to shield them, for in this case the temperature of the air does not at all represent that of the plants. In this respect the conditions of vegetation would be the same at each

locality about the time of the winter awakening, and we should particularly consider the temperature that follows after the thermometer has passed the freezing point, as well as the quantity of light radiated by the sun.

It must therefore be admitted that cold, as long as it does not destroy the life of the plant, may be more or less severe or more or less prolonged, and thus lower the average yearly temperature, without causing any marked difference in the epochs of vegetation. This reflection explains, independent of all hypothesis, that for any equable mean annual temperature the acceleration in vegetation should be in favor of localities where the annual variation is the greatest, particularly in northern countries, where the frost prevails during many months of the year and where duing many of the following months the sunlight never ceases to fill the sky. Admitting the hypothesis that the action is proportional to the sum of the squares of the temperatures, the results are still more positive; for, other things being equal, the greater the annual variation the greater will be the sum of the square of the positive ordinates in the curves of temperatures.

I will now present some conclusions that one can deduce from all that precedes. I must first of all warn my readers that this work must be considered only as an attempt to solve a problem as difficult as it is interesting, the principal elements for the solution of which are still wanting.

1. A great number of factors combine to produce variations in the periodic phenomena of vegetation, the most important of which in our climate is temperature.

2. It may be estimated that the progress of vegetation is in proportion to the sum of the temperatures, or, better, to the sum of the squares of temperatures, calculated above the freezing point, starting with the epoch of the awakening of vegetation after the winter sleep.

3. The cold of winter, if it does not injure the vitality of the plant, does not cause any perceptible retardation in its future development, particularly if the ground has been covered with snow.

The effects that can be produced by the cold of winter must, however, be considered, and especially the condition of the plant when it entered upon its winter sleep, a condition which should correspond to a certain sum of acquired temperatures (or heat stored up). As to the ripening of the harvest and because plants develop under the influence of the sun, we must consult a thermometer exposed to its direct action, and not a thermometer exposed to its direct action, and not a thermometer placed in the shade, as is commonly done.

4. The temperatures at night are not comparable with those of the day as to their effects on vegetation. The quantity of light received by the plants must also be taken into consideration.

5. An increase of 1° in latitude produces about the same retardation in vegetation as an increase in elevation of 100 meters; that is to say, in our climate, a retardation of about four days.

This result should be looked upon as only a kind of average of quantities that vary during the year, the differences of latitude and elevation having scarcely any real influence further than as they produce differences of temperature.

6. The variations of temperature, other things being equal, are

favorable to vegetation, and the same may be said of high plateaus where radiation is more powerful.

7. The isanthesic lines, or lines of simultaneous flowering, do not preserve any parallelism at different periods of the year; thus, the line which shows where the lilac blooms on a given day of the month passes ten days afterwards through another series of places where the same phenomena is then occurring.

Now, the zone comprised between these two lines has not the same breadth throughout its whole extent, as would be the case with a zone between two parallels of latitude. It is not even constant, since, for example, a month later the isanthesic lines will have quite different forms, and localities that were backward as compared with others may then be in advance.

8. The falling of the leaves is a phenomenon which in our climate depends as much upon the current temperature as upon those which have preceded. It is generally controlled by the first cold of autumn.

FRITSCH.

Karl Fritsch (1881) gives the results of about ten years' observations of plants growing in the Botanical Garden at Vienna (1852–1861). His list of plants embraced all those recorded in the previous lists of Quetelet, Sendtner (1851), and his own, in all 1,600 species and varieties, but of which he has only used 889. The epochs observed by him, as uniformly as possible throughout the ten years, were the following:

(1) The first visibility of the upper surface of the leaf.
(2) The complete development of the first flower.
(3) The complete ripening of the first fruit.
(4) The date at which a tree or bush has lost all of its foliage.

Having endeavored in vain to establish a connection between the moisture of the air and the growth of the plant, and finding it impracticable to take account of the moisture in the earth, Fritsch resolved to reject observations made during special droughts or floods or other abnormal conditions and to consider only the sum of the average daily temperatures. These mean daily temperatures he deduced from the observations at 6 a. m. and 2 and 10 p. m., made at the Central Meteorological Institution in Vienna, where the thermometer was about 50 feet above the ground. The summation of the mean daily temperatures for comparison with phenological phenomena counts from the 1st of January to the date of the observed epoch, and omits all days whose mean temperatures are 0° Réaumur or lower than that. A comparison of the observations made on successive years on the same plant shows that the time of blossoming is uncertain by only one or two days in 96 per cent of all the plants, and the so-called "temperature" or "thermal constant" is uncertain by 3 per cent of its amount or less, in 97 per cent of all the plants. Similarly, for dates of ripen-

ing of fruits the dates of ripening as predicted by the temperature constants have an uncertainty of one or two days only in 94 per cent of the cases. In the choice of the date from which to begin taking the sum of the mean daily temperatures, it would seem that for annual plants the date of sowing the seed would be proper, but that for perennial plants the whole winter since the end of the preceding growing season would be proper; but instead of the latter, Fritsch has adopted that epoch at which the mean temperature of the day has its minimum value in the course of its annual variation, and this, combined with the ease of computation, leads him to adopt the 1st of January for all perennials. For the biennials and the annuals he would have preferred to count from the time of sowing the seed, but as the latter date was frequently not recorded and as most of the temperatures are below freezing in the early part of the year, he finds no large error introduced by adopting the 1st of January for these also, and this is very nearly equivalent to Quetelet's method of counting from the time of the permanent awakening of the activity of the plant in the spring.

In the following list I have given all of Fritsch's results, and with reference to the practical application of these figures to the prediction of similar phenomena elsewhere quote his statement that he had convinced himself in many ways that the trees and shrubs observed by him in the Botanical Gardens at Vienna blossomed at the same time as those in the open country, but for all herbs this is true to a less extent, and only in a few cases are the departures important.

Although many plants do not ripen in the short season at Vienna, yet he was able to determine their thermal constants for the date of blossoming.

In general the plants and their seed had by long cultivation in Vienna become acclimated to that locality, so that by applying Linsser's theorems to Fritsch's results they become applicable to the phenomena that would be manifested by these plants in other parts of the world.

As concerns the temperature of the soil, Fritsch states that the perennial grasses were partly shaded by trees until 1852, after which they were cultivated in a sunny spot. The annual grasses were uniformly in a sunny region, slightly inclined toward the north.

The orders or families, with the genera and species and sometimes varieties included within them, are arranged in the table as given by Fritsch, who states that it is in accordance with the natural system of Endlicher, which is generally adopted in Austria as preferable to a chronological or alphabetical. But for the convenience of American readers I have added to each of Fritsch's orders the number by which it is designated on pages 5 and 736 of Gray's Manual of

the Botany of the Northern United States, sixth edition, 1890, as revised by Watson and Coulter. These numbers will be found in the brackets following the names of the orders in the following table, e. g., [G. 129].

Thermal constants for the blossoming and ripening of 889 plants (or the sums of the mean daily temperature above zero degrees Réaumur counting from January 1st), as determined by Karl Fritsch from observations in the Botanical Garden, in Vienna, during the years 1852–1861, inclusive.

[See Denkschriften, Akad. Vienna, 1863, Vol. XXI.]

[See end of table for footnotes.]

Designation of plant: Order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Contant.
I. *Gramineæ* [*G. 129*].		° *Réaum.*		° *Réaum.*
(1) Zea mays L. (sown Apr. 29)	July 20	1,082	....	....
(2) Alopecurus pratensis L	May 5	425	....	....
(3) Phleum pratense L. var. nodosom	June 19	981	July 28	1,595
(4) Phalaris arundinacea L	June 10	824	July 2	1,143
(5) Holcus lanatus L	June 8	812	June 28	1,111
(6) Holcus mollis L	July 2	1,144	....	....
(7) Anthoxanthum odoratum L	May 15	478	June 10	838
(8) Panicum miliaceum L. (Apr. 26)	July 7	907	July 22	1,184
(9) Stipa capillata L	June 27	1,095	July 24	1,532
(10) Stipa pennata L	June 1	698	July 1	1,154
(11) Agrostis alba L. (A. stolonifera L. γ, flagellare)	June 29	1,091	July 16	1,376
(12) Agrostis vulgaris With	July 4	1,157	July 25	1,500
(13) Calamagrostis Epigejos Roth	July 5	1,244	July 22	1,488
(14) Avena pratensis L	May 25	618	June 11	873
(15) Avena sativa L. (sown Apr. 12)	July 5	984	July 20	1,200
(16) Sesleria caerulea Arduin	Apr. 9	221	May 13	504
(17) Poa compressa L	June 16	922	July 16	1,371
(18) Poa nemoralis L	June 4	765	June 26	1,075
(19) Poa pratensis L	May 27	631	June 15	925
(20) Briza media L	June 2	760	June 17	989
(21) Melica ciliata L	June 8	856	....	....
(22) Dactylis glomerata L	May 27	677	June 20	999
(23) Cynosurus cristatus L	June 17	937	July 14	1,371
(24) Festuca glauca Lam	May 31	707	June 20	984
(25) Festuca ovina L	May 28	655	June 16	922
(26) Festuca rubra L	June 3	754	June 24	1,055
(27) Bromus erectus Huds	....do ...	751	July 1	1,155
(28) Lolium perenne L	June 9	784	July 9	1,269
(29) Triticum caninum L	June 5	787	July 3	1,272
(30) Triticum pinnatum Mönch var. caespitosum	June 8	823	June 29	1,115
(31) Triticum repens L	June 18	982	July 9	1,267
(32) Triticum vulgare Vill. hibernum	June 2	758	July 3	1,183
(33) Secale cereale L. hibernum	May 25	626	June 29	1,145
(34) Elymus arenarius L	June 2	749	Aug. 19	1,990
(35) Hordeum vulgare L. (Apr. 12)	June 15	648	July 16	1,150
(36) Andropogon Ischaemum L	Aug. 5	1,671	Aug. 16	2,046

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: Order, genus, and species.	Flowering. Date.	Flowering. Constant.	Ripening. Date.	Ripening. Constant.
II. *Cyperaceæ* [*G. 128*].		°*Réaum.*		°*Réaum.*
(37) Carex distans L	May 7	417	June 12	897
(38) Carex glauca Scopol	Apr. 26	338	...do....	889
(39) Carex hirta L	May 10	478	June 26	1,101
(40) Carex hornschuhiana Hoppe	Apr. 25	309	June 12	880
(41) Carex humilis Leyss	Apr. 1	169		
(42) Carex intermedia Good	May 7	417		
(43) Carex maxima Scop	May 21	542	June 26	1,070
(44) Carex montana L	Apr. 7	214		
(45) Carex paludosa Good	May 7	449	June 27	1,002
(46) Carex pilulifera L	Apr. 12	234		
(47) Carex praecox Jacq	Apr. 13	139		
(48) Carex Schreberi Schrank	Apr. 25	345		
(49) Carex supina Wahlb	Apr. 2	172		
(50) Carex tomentosa L	Apr. 29	352	June 9	871
(51) Cyperus longus L	July 6	1,224		
III. *Commelynaceæ* [*G. 120*].				
(52) Tradescantia virginica L. var. rubra	May 30	670	July 6	1,198
IV. *Alismaceæ* [*G. 125*].				
(53) Alisma plantago L	July 23	1,517	Aug. 18	2,016
V. *Melanthaceæ* [*G. —; see G. 116.*]				
(54) Veratrum album L	(54)	(54)		
(55) Veratrum nigrum L	July 13	1,358	Sept. 13	2,304
(56) Bulbocodium soboliferum End	Mar. 18	107		
(57) Colchicum autumnale L. (57)	Sept. 2	2,134	June 12	903
(58) Colchicum autumnale L. var. albiflorum	Sept. 10	2,243		
(59) Colchicum autumnale L. var. subtessellatum	Sept. 17	2,328		
VI. *Liliaceæ* [*G. 116*].				
(60) Erythronium dens canis L	Mar. 31	141		
(61) Tulipa gesneriana L	May 12	486		
(62) Tulipa oculus solis St. Amand	May 11	470		
(63) Tulipa praecox Tenor	Apr. 22	306	June 1	685
(64) Tulipa silvestris L	May 2	368	July 6	1,195
(65) Tulipa suaveolens Roth	Apr. 19	273		
(66) Fritillaria imperialis L	Apr. 21	273		
(67) Fritillaria meleagris L	...do...	284		
(68) Lilium bulbiferum L	June 5	759	Sept. 7	2,247
(69) Lilium candidum L	June 23	1,066		
(70) Lilium croceum Chaix. var. saturatum	June 3	754	Aug. 8	1,754
(71) Lilium martagon L	June 16	927		
(72) Lilium monadelphum M. Bieberst	May 26	653	July 27	1,576
(73) Funkia grandiflora	Aug. 19	1,935		
(74) Funkia lanceifolia Sieb	Aug. 5	1,718		
(75) Funkia ovata Spreng	July 11	1,314		
(76) Funkia sieboldi Lindl. var. cucullata	June 22	1,025		
(77) Funkia subcordata Spr	Aug. 23	1,957		
(78) Muscari azurea Fenzl	Mar. 16	92		
(79) Muscari botryoides D. C. (later under the name Muscari racemosum parviflorum).	Apr. 18	249	June 16	926
(80) Muscari comosum Mill	June 8	821	July 28	1,516
(81) Muscari moschatum Desf	Apr. 21	332		

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering. Date.	Flowering. Constant.	Ripening. Date.	Ripening. Constant.
VI. *Liliaceæ* [*G. 116*]—Continued.		°*Réaum.*		°*Réaum.*
(82) Muscari racemosum Willd	Apr. 12	223	June 17	955
(83) Hyacinthus amethystinus L	May 16	542	....	....
(84) Hyacinthus orientalis L	Apr. 10	224	....	....
(85) Agraphis companulata Lk	May 10	463	....	....
(86) Agraphis patula Beh	...do...	457	June 26	1,091
(87) Scilla amoena L	Apr. 27	339	June 7	791
(88) Scilla autumnalis L	Sept. 7	2,376	....	....
(89) Scilla italica L	Apr. 21	300	....	....
(90) Scilla pratensis M. and R	May 20	584	....	....
(91) Ornithogalum pyrenaicum L. var. narbonense, monstrosum	May 31	732	July 22	1,466
(92) Ornithogalum umbellatum L	May 12	470	....	....
(93) Myogalum nutans Link	Apr. 15	249	June 3	731
(94) Puschkinia scilloides Willd	Apr. 1	184	....	....
(95) Allium cepa L	July 9	1,274	....	....
(96) Allium fistulosum L. var. altaicum	May 23	603	July 1	1,169
(97) Allium molly L	June 5	785	....	....
(98) Allium paniculatum Aut. (?)	July 23	1,487	....	....
(99) Allium porrum L	June 27	1,104	Aug. 28	2,076
(100) Allium roseum L. var. bulbiferum	May 31	718	June 28	1,120
(101) Allium sativum L	July 24	1,477	....	....
(102) Allium schönoprasum L	June 23	1,051	July 29	1,617
(103) Allium scorodoprasum L	July 14	1,314	....	....
(104) Allium serotinum Schleich	Aug. 24	2,027	Oct. 15	2,642
(105) Allium ursinum L	May 14	520	June 22	1,015
(106) Allium victorialis L	May 18	503	June 24	1,077
(107) Eremerus caucasicus Stev	May 19	567	July 2	1,180
(108) Asphodelus ramosus L	July 19	1,479	....	....
(109) Asphodelus luteus L	May 10	451	July 18	1,416
(110) Hemerocallis flava L	June 3	737	July 23	1,480
(111) Hemerocallis fulva L	June 23	1,042	....	....
(112) Hemerocallis graminea Andrev. var. bracteosa	May 23	605	July 14	1,490
(113) Anthericum liliago L	June 3	750	July 23	1,508
(114) Anthericum ramosum L	July 6	1,242	Aug. 29	2,096
(115) Asparagus officinalis L	May 20	572	June 25	1,068
VII. *Smilaceæ* [*G. —; see G. 116*].				
(116) Convallaria majalis L	May 8	428	Aug. 8	1,759
(117) Convallaria polygonatum Desf	May 7	418	Aug. 5	1,699
(118) Smilacina racemosa Desf	May 18	542	....	....
VIII. *Dioscoreæ* [*G. 115*].				
(119) Tamus communis L	May 24	641	Aug. 12	1,797
IX. *Irideæ* [*G. 113*].				
(120) Iris biflora (Aut.?)	May 9	432	....	....
(121) Iris biglumis Vahl	Apr. 28	359	....	....
(122) Iris germanica L. var. saturata	May 14	491	July 29	1,620
(123) Iris notha M. Bieb. var. livescens	June 9	853	....	....
(124) Iris pseudacorus L	May 28	656	....	....
(125) Iris pumila L	Apr. 22	296	....	....
(126) Iris sibirica L. var. saturata	May 11	578	July 28	1,547
(127) Iris virginica Gronov	June 8	746	....	....
(128) Iris xyphium L	June 10	868	....	....
(129) Gladiolus communis L	June 13	879	July 29	1,613

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
IX. *Irideæ* [*G. 113*]—Continued.		°*Réaum.*		°*Réaum.*
(130) Gladiolus segetum Ker	June 7	824		
(131) Crocus imperati Tenor	Oct. 21	2,730		
(132) Crocus luteus Lam	Mar. 16	103		
(133) Crocus nudiflorus Smith	Oct. 21	2,701		
(134) Crocus odorus Bor	Oct. 13	2,614		
(135) Crocus pallasii Goldb	Oct. 4	2,502		
(136) Crocus præcox Hock	Mar. 3	67		
(137) Crocus sativus L	Oct. 6	2,529		
(138) Crocus sauveolens Bertol	Mar. 18	111		
(139) Crocus speciosus Host	Sept. 23	2,406		
(140) Crocus susianus Ker	Mar. 5	81		
(141) Crocus thomasii Tenor	Oct. 13	2,543		
(142) Crocus variegatus Hoppe	Mar. 28	144		
(143) Crocus vernus Willd. var. lilacinus	...do...	142		
(144) Crocus vernus Willd., β, albiflorus	Mar. 24	162		
(145) Crocus versicolor Ker	Mar. 21	117		
X. *Amaryllideæ* [*G. 114*].				
(146) Galanthus nivalis L	Mar. 3	73		
(147) Galanthus plicatus M. Bieb	Mar. 1	68		
(148) Leucojum vernum L	Mar. 20	120		
(149) Sternbergia colchiciflora M. et K	Sept. 17	2,385		
(150) Sternbergia lutea Schult. fil	Sept. 25	2,419		
(151) Narcissus biflorus Curt	May 10	464		
(152) Narcissus grandiflorus Hav	Apr. 29	366		
(153) Narcissus italicus Kor	Apr. 23	320		
(154) Narcissus major Curt	Apr. 20	265		
(155) Narcissus odorus L	Apr. 16	298		
(156) Narcissus poeticus L	Apr. 28	348		
(157) Narcissus præcox Tenor	Apr. 18	323		
(158) Narcissus pseudonarcissus L. var. plenus	...do...	285		
(159) Narcissus seratus Hav	...do...	218		
(160) Narcissus tazeta L	Apr. 16	311		
XI. *Aroideæ* [*G. —; see G. 123*].				
(161) Aurum maculatum L	May 18	548	July 14	1,377
(162) Acorus calamus L	May 27	640		
XII. *Typhaceæ* [*G. 122*].				
(163) Typha angustifolia L	June 14	923		
(164) Typha latifolia L	June 11	873	Oct. 26	2,737
XIII. *Cupressinæ* [*G. —; see G. 107*].				
(165) Juniperus communis L. var. vulgaris	Apr. 30	372	Aug. 26	2,025
(166) Juniperus phœnicea L. ♂	Apr. 13	190		
XIV. *Abietinæ* [*G. —; see G. 107*].				
(167) Pinus cedrus L	Sept. 25	2,393		
(168) Pinus cembra L	(168)	(168)		
(169) Pinus laricio Poir. var. gibbosa	May 20	565		
(170) Pinus larix L	Apr. 14	215		
(171) Pinus nigra Ait	May 5	393		
(172) Pinus picea L	Apr. 28	353		
(173) Pinus pumilis Hänke	May 24	630		
(174) Pinus silvestris L	May 17	517		
(175) Pinus strobus L. var. compressa	(175)	(175)		
(176) Pinus uncinata Ramond	May 24	603		

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XV. *Taxineæ* [*G.* —; *see G.* 107].		°*Réaum.*		°*Réaum.*
(177) Taxus baccata L	Mar. 28	149	Aug. 18	1,873
(178) Salisburia adiantifolia Sm. ♂	May 11	431	....	....
XVI. *Betulaceæ* [*G.* —; *see G.* 103].				
(179) Betula alba L. var. dalecarlica	(179)	(179)	....	....
(180) Alnus cordifolia Tenor	Apr. 8	199	Sept. 30	2,524
(181) Alnus glutinosa L. var. pinnatifida	Mar. 11	97	Sept. 23	2,404
(182) Alnus subcordata C. H. Meyer	Feb. 11	56	Sept. 27	2,436
XVII. *Cupuliferæ* [*G.* 105].				
(183) Ostrya vulgaris Willd	May 3	381	....	....
(184) Carpinus betulus L	Apr. 20	279	Aug. 20	1,836
(185) Carpinus orientalis Lam	May 3	370	....	....
(186) Corylus americana Rich	Mar. 21	138	....	....
(187) Corylus avellana L. var. globosa	Mar. 1	72	....	....
(188) Corylus colurna Willd	...do..	72	....	....
(189) Quercus alba L	(189)	(189)	....	....
(190) Quercus cerris L	May 12	475	Sept. 21	2,335
(191) Quercus pedunculata Ehrh	May 6	420	Sept. 14	2,236
(192) Fagus silvatica L	May 3	380	Aug. 2	1,617
(193) Fagus silvatica L. var. pendula	May 7	425	....	....
XVIII. *Ulmaceæ* [*G.* —; *see G.* 99].				
(194) Ulmus campestris L. montana tortuosa	Mar. 30	163	May 18	540
(195) Ulmus effusa Willd	Mar. 31	162	May 20	574
XIX. *Celtideæ* [*G.* —; *see G.* 99].				
(196) Celtis australis L	Apr. 24	231	....	....
(197) Celtis occidentalis L	Apr. 29	350	Aug. 15	1,806
XX. *Moreæ* [*G.* —; *see G.* 99].				
(198) Morus alba L. morettiana	May 15	509	June 18	970
(199) Morus alba L. fructu nigro	May 16	545	June 21	1,015
(200) Morus scabra Willd	May 17	549	July 8	1,280
(201) Maclura aurantiaca Nuttal ♀	June 7	818	....	....
(202) Broussonetia papyrifera Vent. ♂ cucullata	May 11	491	....	....
(203) Ficus carica L	(203)	(203)	....	....
XXI. *Cannabineæ* [*G.* —; *see G.* 99].				
(204) Humulus lupulus L. ♂	Aug. 3	1,658	....	....
XXII. *Plataneæ* [*G.* 110].				
(205) Platanus occidentalis L	May 10	467	....	....
(206) Platanus orientalis L., β, acerifolia, ββ, grandifolia	May 6	420	....	....
XXIII. *Salicineæ* [*G.* 104].				
(207) Salix babylonica L. ♀	Apr. 16	262	....	....
(208) Salix daphnoides Vill. ♂	Mar. 31	141	....	....
(209) Salix purpurea L	Apr. 14	229	May 19	525
(210) Salix repens L. ♂	Apr. 15	238	....	....
(211) Populus alba L. ♀ anglica	Apr. 4	179	....	....
(212) Populus balsamifera L. ♂ β suaveolens	Apr. 12	212	....	....
(213) Populus canescens Smith. ♂ belgica	Mar. 28	145	....	....
(214) Populus dilatata Ait. ♀ ♂	Apr. 9	220	May 31	703
(215) Populus græca Ait. ♀	Mar. 27	131	May 1	371
(216) Populus nigra L. ♀	Apr. 12	236	May 30	683
(217) Populus tremula L. ♂ ♀	Mar. 26	137	May 8	418

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XXIV. *Chenopodeæ* [*G. 87*].		°*Réaum.*		°*Réaum.*
(218) Spinacia oleracea L	May 12	484	June 21	1,018
(219) Beta vulgaris L	June 11	816	July 18	1,412
XXV. *Polygoneæ* [*G. 89*].				
(220) Rheum emodi Wall	June 4	770	....	....
(221) Rheum hybridum Ait. (later R. rhaponticum L.)	May 16	494	June 21	1,021
(222) Rheum palmatum L. (also later R. rhaponticum L.)	May 17	501	June 18	983
(223) Rheum rhaponticum L	May 11	468	June 15	921
(224) Rheum undulatum L	May 13	480	June 17	956
(225) Polygonum amphibium L	June 28	1,165	....	....
(226) Polygonum bistorta L	May 21	583	June 14	946
(227) Polygonum fagopyrum L. (sown Apr. 24)	June 10	552	July 18	1,096
(228) Rumex acetosa L. ♀ ♂	June 1	709	July 17	1,399
(229) Rumex acetosella L. multifidus	May 27	661	....	....
(230) Rumex crispus L	June 4	752	July 2	1,145
(231) Rumex nemolapathum Ehrh	June 18	972	July 14	1,412
(232) Rumex patientia L. conferta	May 27	659	June 28	1,121
(233) Rumex scutatus L	May 26	627	June 20	997
XXVI. *Daphnoideæ* [*G. —; see G. 94*].				
(234) Daphne alpina L	May 8	432	June 21	1,011
(235) Daphne laureola L	Mar. 28	150	....	....
(236) Daphne mezereum L	Jan. 25	36	June 8	804
XXVII. *Elæagneæ* [*G. 95*].				
(237) Hippophæ rhamnoides L. ♂	May 10	383	....	....
(238) Elæagnus hortensis M. B. augustifolius	June 7	814	Sept. 12	2,267
XXVIII. *Aristolochieæ* [*G. 91*].				
(239) Aristolochia clematitis L	May 11	471	Sept. 2	2,130
(240) Aristolochia sipho L	May 21	576	....	....
XXIX. *Plantagineæ* [*G. 83*].				
(241) Plantago cynops L	May 18	534	July 9	1,298
(242) Plantago lanceolata L	May 8	425	June 28	1,157
(243) Plantago media L	May 25	620	July 16	1,373
(244) Plantago saxatilis M. Bieb	Apr. 28	359	June 29	1,148
XXX. *Plumbagineæ* [*G. 60*].				
(245) Armeria vulgaris Willd	May 19	566	June 21	1,036
(246) Statice caspia Willd	July 24	1,544	....	....
(247) Statice incana	June 14	927	July 28	1,564
(248) Statice latifolia Sm	July 22	1,476	....	....
(249) Statice limonium L	July 11	1,332	....	....
XXXI. *Valerianeæ* [*G. 53*].				
(250) Centranthus ruber D. C	June 1	746	July 30	1,626
(251) Valeriana officinalis L	June 7	801	July 1	1,179
(252) Valeriana phu L	May 22	586	June 26	1,127
XXXII. *Dipsaceæ* [*G. 229*].				
(253) Dipsacus fullonum L	July 11	1,313	Aug. 10	1,741
(254) Dipsacus sylvestris Huds	July 15	1,384	Aug. 11	1,792
(255) Cephalaria tatarica Schrad. gigantea	July 2	1,264	....	....
(256) Knautia ciliata Coult	June 4	782	....	....
(257) Scabiosa caucasica M. Bieb. heterophylla	July 16	1,376	Aug. 4	1,689
(258) Scabiosa columbaria Coult	June 30	1,130	July 22	1,482
(259) Scabiosa ochroleuca L	June 29	1,127	July 30	1,597
(260) Scabiosa succisa L	Aug. 4	1,677	Sept. 6	2,188

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XXXIII. *Compositæ* [*G. 55*].		°*Réaum.*		°*Réaum.*
(261) Eupatorium ageratoides L	July 23	1,481	Sept. 2	2,191
(262) Eupatorium cannabinum L	July 5	1,231	Aug. 9	1,745
(263) Eupatorium purpureum (Aut.?)	Aug. 9	1,774	Sept. 19	2,351
(264) Eupatorium syriacum Jacq	Sept. 24	2,375	....	....
(265) Tussilago petasites L	Apr. 6	194	May 2	411
(266) Tussilago farfara L	Mar. 10	94	Apr. 17	202
(267) Aster alpinus L	May 15	479	July 2	1,155
(268) Aster amellus L. latifolius	Aug. 13	1,904	Oct. 4	2,503
(269) Aster grandiflorus L	Oct. 18	2,579	....	....
(270) Aster novæ angliæ Ait	(270)	(270)	....	....
(271) Aster novi belgii Nees	(271)	(271)	....	....
(272) Aster pilosus Willd	Sept. 12	2,248	....	....
(273) Aster pyrenæus Desf	Sept. 9	2,179	....	....
(274) Erigeron acre L	June 14	902	July 11	1,309
(275) Erigeron canadensis L	July 9	1,264	July 22	1,459
(276) Solidago altissima L	Aug. 21	1,921	Sept. 26	2,375
(277) Solidago canadensis L	Aug. 4	1,674	Sept. 7	2,178
(278) Solidago confertiflora D. C	May 24	626	June 22	1,029
(279) Solidago lævigata Ait	Oct. 15	2,613	....	....
(280) Solidago rigida Ait	Aug. 10	1,760	Oct. 18	2,673
(281) Solidago virgaurea L	June 26	1,082	Aug. 13	1,799
(282) Linosyris vulgaris Cass	Aug. 31	2,093	Oct. 5	2,541
(283) Inula britannica L	July 23	1,458	Aug. 26	1,968
(284) Inula germanica L	July 2	1,182	Aug. 19	1,946
(285) Inula helenium L	July 11	1,310	Aug. 11	1,804
(286) Inula hirta L	June 3	754	Aug. 13	1,797
(287) Inula oculus christi L	June 29	1,003	July 24	1,543
(288) Inula salicina L	June 22	1,026	Aug. 20	1,952
(289) Inula squarrosa L	July 8	1,253	Aug. 25	2,035
(290) Inula thapsoides Spr	July 19	1,449	Sept. 13	2,215
(291) Silphium laciniatum L	July 29	1,600	Sept. 23	2,411
(292) Silphium integrifolium Michx	July 10	1,313	Sept. 7	2,192
(293) Silphium perfoliatum L. hornemanni	July 5	1,232	Aug. 21	1,963
(294) Silphium ternatum L. atropurpureum	May 3	1,189	....do...	1,967
(295) Heliopsis scabra Dun	July 11	1,336	Sept. 1	2,066
(296) Echinacea purpurea Mönch	Aug. 2	1,653	....	....
(297) Rudbeckia fulgida Ait	June 25	1,049	....	....
(298) Rudbeckia hirta L	June 26	1,099	Aug. 2	1,651
(299) Rudbeckia speciosa Wenderoth	July 27	1,520	Sept. 21	2,382
(300) Obeliscaria pinnata Cass	July 18	1,468	....	....
(301) Calliopsis bicolor Reichb. (sown June 13)	Sept. 13	1,394	....	....
(302) Coreopsis lanceolata L	June 22	1,026	July 25	1,403
(303) Helianthus annuus L	Aug. 16	1,511	Sept. 15	1,947
(304) Helianthus giganteus L (304)	Aug. 13	1,783	....	....
(305) Helianthus grosse-serratus Mert	Oct. 2	2,426	....	....
(306) Helianthus multiflorus L	July 22	1,472	Sept. 19	2,303
(307) Helianthus orygalis D. C	Sept. 15	2,299	....	....
(308) Helianthus tuberosus L	(308)	(308)	....	....
(309) Helianthus tracheliformis Willd	Aug. 6	1,712	....	....
(310) Bidens tripartita L	Aug. 25	2,005	Sept. 26	2,437
(311) Verbesina phætusa Cassin	Oct. 10	2,508	....	....
(312) Tagetes patula L. (sown June 13)	Aug. 10	886	....	....
(313) Gaillardia aristata Pursh	June 9	833	July 12	1,334

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XXXIII. *Compositæ* [*G. 55*]—Continued.		°*Réaum.*		°*Réaum.*
(314) Gaillardia drummondii D. C	June 5	800		
(315) Gaillardia lanceolata Mich	June 4	778	July 12	1,331
(316) Gaillardia pulchella Fouger	June 5	778	July 8	1,279
(317) Helenium autumnale L. serratifolium	Aug. 1	1,655	Aug. 31	2,071
(318) Anthemis nobilis L	June 27	1,108	July 28	1,605
(319) Anthemis tinctoria L. pallida	June 11	856	July 25	1,515
(320) Achillea magna Hänke	June 12	830	Aug. 10	1,770
(321) Achillea millefolium L	June 21	1,006	Aug. 12	1,807
(322) Achillea nobilis L	June 17	908	July 28	1,599
(323) Achillea tomentosa L	May 24	611	July 4	1,202
(324) Anacyclus pyrethrum D. C	May 20	567		
(325) Ptarmica alpina D. C	June 23	1,002	Aug. 24	2,018
(326) Ptarmica vulgaris D. C	do	1,037	Aug. 21	1,968
(327) Matricaria chamomilla L	May 19	556	July 19	981
(328) Pyrethrum chinense Sab	Oct. 25	2,696		
(329) Pyrethrum parthenium L	June 9	845	July 17	1,427
(330) Chrysanthemum coronarium L. (sown June 17)	Aug. 25	1,117		
(331) Artemisia absinthium L	Aug. 10	1,803		
(332) Artemisia vulgaris L. coarctata	July 19	1,446	Sept. 16	2,377
(333) Tanacetum leucanthemum Schultz	May 21	565	June 27	1,092
(334) Tanacetum vulgare L	July 17	1,422	Aug. 21	1,988
(335) Doronicum pardalianthes L	May 6	413	May 29	693
(336) Cacalia suaveolens L	July 25	1,510	Aug. 30	2,066
(337) Senecio aquaticus Huds	June 5	753	Sept. 12	1,307
(338) Senecio coriaceus Ait	June 23	1,045	July 15	1,379
(339) Senecio jacobæa L	July 27	1,518	Aug. 22	1,918
(340) Senecio jacobæa L. campestris	June 7	830	July 13	1,305
(341) Echinops ritro L. polycephala	July 22	1,467	Aug. 20	1,963
(342) Echinops sphaerocephalus L	July 9	1,285	Aug. 23	2,002
(343) Haplotaxis albescens D. C	July 28	1,640		
(344) Carlina vulgaris L	do	1,612	Sept. 6	2,[illegible]86
(345) Centaurea aspera L	June 27	1,086		
(346) Centaurea calocephala D. C. mixta	June 23	1,057	July 22	1,489
(347) Centaurea dealbata Willd. var. major	May 24	632	June 15	926
(348) Centaurea Jacea L. lacera, incana	July 13	1,351		
(349) Centaurea lagdunensis? (var. of C. montana?)	May 2	575		
(350) Centaurea rupestris L. aculeosa	June 17	952	July 18	1,414
(351) Cnicus benedictus L. (sown May 5)	July 9	896		
(352) Carthamus tinctorius L. (sown May 4)	July 21	1,071		
(353) Onopordon acanthium L. horridum	July 7	1,215	Aug. 7	1,722
(354) Onopordon virens D. C	June 27	1,088	July 30	1,590
(355) Cynara cardunculus L	July 26	1,551	Sept. 14	2,273
(356) Cynara scolymus L	July 31	1,624	Sept. 28	2,442
(357) Carduus crispus L	July 10	1,275	Aug. 4	1,690
(358) Cirsium acaule All	July 13	1,321	Aug. 9	1,761
(359) Cirisum bulbosum D. C	June 18	970	July 6	1,251
(360) Cirsium lanceolatum Scop	July 24	1,522	Aug. 21	1,983
(361) Cirsium pannonicum D. C	July 7	1,247	July 22	1,495
(362) Cirsium pratense D. C	July 18	1,400		
(363) Lappa major Gärtn	July 15	1,370	Aug. 21	1,948
(364) Lappa tomentosa Lam	July 14	1,364	do	1,941
(365) Rhaponticum cinaroides Lessing	July 8	1,301		
(366) Rhaponticum pulchrum Fischer et Meyer	June 13	909	July 14	1,343

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XXXIII.—*Compositæ* [*G. 55*]—Continued.		°*Réaum.*		°*Réaum.*
(367) Serratula coronata (L.?)	July 27	1,550	....	....
(368) Serratula tinctoria L	...do...	1,515	Aug. 21	1,950
(369) Catananche caerulea L	June 22	999	Aug. 7	1,709
(370) Cichorium intybus L	June 24	1,065	July 25	1,544
(371) Hypochaeris radicata L	June 7	817	June 27	1,103
(372) Podospermum jacquinianum, Koch	May 14	503	....	....
(373) Tragopogon porrifolius L	May 31	698	June 16	958
(374) Tragopogon pratensis L	May 22	596	July 16	975
(375) Scorzonera austriaca L	May 13	486	....	....
(376) Scorzonera hispanica L	May 27	657	June 25	1,070
(377) Picridium tingitanum Desf. (sown June 18)	Aug. 12	826	Sept. 9	1,216
(378) Lactuca sativa L	July 5	1,182	July 26	1,532
(379) Lactuca virosa L	June 27	1,110	July 18	1,418
(380) Chondrilla juncea L	July 22	1,534	....	....
(381) Taraxacum dens leonis Desf	Apr. 21	299	May 8	443
(382) Hieracium aurantiacum L	May 30	675	June 20	1,019
(383) Hieracium murorum L	May 19	622	....	....
(384) Hieracium pratense Tausch	May 27	659	June 12	909
(385) Hieracium saxatile Jacq	July 13	1,358	July 30	1,625
(386) Hieracium umbellatum L. pectinatum	Aug. 1	1,732	Aug. 23	2,010
(387) Hieracium virosum Pallas	July 12	1,350	Aug. 11	1,821
XXXIV. *Lobeliaceæ* [*G. 56*].				
(388) Lobelia syphilitica L	July 23	1,501	....	....
XXXV. *Campanulaceæ* [*G. 57*].				
(389) Phyteuma spicatum L	May 23	589	July 10	1,306
(390) Campanula aliariaefolia Willd	June 23	1,050	....	....
(391) Campanula bononiensis L. ruthenica	July 2	1,199	....	....
(392) Campanula caespitosa Scop. alba	July 4	1,210	....	....
(393) Campanula glomerata L	...do...	1,201	....	....
(394) Campanula media L	June 11	861	....	....
(395) Campanula pyramidalis L	July 23	1,543	....	....
(396) Campanula rapunculus L	June 4	781	July 9	1,297
(397) Campanula trachelium (L.)	July 5	1,222	Aug. 24	2,030
XXXVI. *Rubiaceæ* [*G. 52*].				
(398) Galium mollugo L	June 2	708	July 21	1,462
(399) Galium verum L. brachyphyllum	June 29	1,149	....	....
(400) Rubia tinctorum L	June 28	1,118	Aug. 18	1,876
(401) Asperula galioides M. Bieb	July 2	1,172	Aug. 23	2,050
(402) Asperula odorata L	May 7	453	....	....
(403) Asperula tinctoria L	May 26	651	July 21	1,480
(404) Cephalanthus occidentalis R. S	July 21	1,513	....	....
XXXVII. *Lonicereæ* [*G. —; see G. 51*].				
(405) Lonicera caprifolium L	June 1	701	....	....
(406) Lonicera grata Ait	June 16	946	....	....
(407) Lonicera iberica M. Bieb	June 5	783	....	....
(408) Lonicera periclymenum L	June 11	863	July 28	1,592
(409) Lonicera tatarica L. pallida	May 6	414	June 22	1,076
(410) Lonicera xylosteum L	May 7	421	June 28	1,102
(411) Viburnum lantana L	May 3	389	Aug. 2	1,662

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XXXVII. *Lonicereæ* [*G.* —; *see G. 51*]—Continued.		°*Réaum.*		°*Réaum.*
(412) Viburnum opulus L	May 17	507	July 23	1,482
(413) Sambucus ebulus L	June 23	1,042	Aug. 11	1,817
(414) Sambucus nigra L	May 22	579	Aug. 7	1,692
(415) Sambucus racemosa L	May 1	350	June 22	1,004
XXXVIII. *Oleaceæ* [*G. 65*].				
(416) Ligustrum vulgare L	June 3	746	Sept. 9	2,254
(417) Fraxinus excelsior L	Apr. 14	248	July 23	1,443
(418) Fraxinus excelsior L. aurea	...do...	277	May 22	590
(419) Fraxinus excelsior L. pendula	Apr. 20	296	July 11	1,281
(420) Fraxinus ornus L	May 18	537		
(421) Fraxinus tamariscifolia Vahl	Apr. 8	222		
(422) Syringa josikea Jacq	May 21	597		
(423) Syringa persica L	May 12	478		
(424) Syringa vulgaris L	May 6	424	Aug. 26	2,014
XXXIX. *Apocynaceæ* [*G. 66*].				
(425) Vinca herbacea M. et K	Apr. 26	337		
(426) Vinca minor L. variegata	Apr. 16	265		
XL. *Asclepiadeæ* [*G. 67*].				
(427) Periploca græca L	June 6	798		
(428) Vincetoxicum fuscatum Endl	May 24	620	Aug. 12	1,816
(429) Vincetoxicum nigrum Mönch	June 2	719	Aug. 20	1,935
(430) Vincetoxicum officinale Mönch	May 16	529	Aug. 24	1,947
(431) Asclepias syriaca L	June 24	1,044		
XLI. *Gentianeæ* [*G. 69*].				
(432) Menyanthes trifoliata L	Apr. 29	358		
XLII. *Labiatæ* [*G. 82*].				
(433) Lavandula spica D. C	Aug. 4	1,696	Sept. 24	2,430
(434) Lavandula vera D. C	June 26	1,093	Aug. 3	1,650
(435) Mentha crispa L	July 14	1,368		
(436) Mentha piperita L	July 22	1,496		
(437) Mentha pulegium L	July 21	1,475		
(438) Mentha rotundifolia L	July 23	1,488		
(439) Lycopus europaeus L	July 5	1,247	Aug. 19	1,931
(440) Salvia argentea L	June 10	879	July 13	1,357
(441) Salvia austriaca L	May 22	606	June 15	929
(442) Salvia glutinosa L	July 27	1,559	Aug. 29	2,052
(443) Salvia officinalis L	June 1	722	July 6	1,241
(444) Salvia pitscheri Torr	Oct. 13	2,616		
(445) Salvia pratensis L	May 16	526	June 9	823
(446) Salvia sclarea Jacq	June 18	958	July 27	1,562
(447) Salvia silvestris L	May 23	608	June 21	1,015
(448) Monarda fistulosa L	July 10	1,294	Aug. 23	1,960
(449) Origanum vulgare L	June 22	1,028	Aug. 9	1,736
(450) Thymus serpyllum L. vulgaris	May 22	589	June 16	1,018
(451) Thymus vulgaris L	June 1	721		
(452) Hyssopus officinalis L	July 1	1,164	Aug. 4	1,712
(453) Calamintha clinopodium Benth	June 20	1,003		
(454) Calamintha grandiflora Mönch	June 6	791		
(455) Calamintha nepeta K. et Hoffm. var. albiflora	July 2	1,183	Aug. 17	1,875

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XLII. *Labiatæ* [*G. 82*]—Continued.		°*Réaum.*		°*Réaum.*
(456) Melissa officinalis L	July 9	1,267	Aug. 6	1,720
(457) Prunella grandiflora Mönch	June 16	933	July 18	1,442
(458) Prunella vulgaris L	June 22	1,017	July 17	1,379
(459) Scutellaria alpina L. lupulina purpurascens	May 22	605	June 22	1,049
(460) Scutellaria galericulata L	July 1	1,166	....	....
(461) Nepeta cataria L	June 25	1,058	July 25	1,536
(462) Nepeta mussini M. Bieb. var. salviaefolia	Apr. 28	379	....	....
(463) Nepeta glechoma Benth	Apr. 10	224	May 31	698
(464) Dracocephalum austriacum L	May 24	613	June 21	1,053
(465) Melittis melissophyllum L	May 19	575	....	....
(466) Physostegia speciosa Sweet	July 13	1,321	Aug. 8	1,746
(467) Lamium orvala L	May 4	400	June 2	763
(468) Leonurus cardiaca L	June 10	839	July 19	1,443
(469) Stachys alpina L. var. intermedia	June 24	1,052	July 27	1,582
(470) Stachys germanica L. var. oblongifolia	June 10	838	July 23	1,529
(471) Betonica officinalis L	June 30	1,149	Aug. 7	1,805
(472) Sideritis scordioides L	June 5	770	July 9	1,285
(473) Marrubium vulgare L	June 7	787	July 17	1,417
(474) Ballota nigra. L	July 1	1,185	Aug. 10	1,766
(475) Phlomis tuberosa L	June 1	722	July 12	1,311
(476) Teucrium chamædrys L	June 22	1,036	Aug. 10	1,796
(477) Teucrium montanum L	June 23	1,045	Aug. 5	1,742
(478) Teucrium scordium L	July 7	1,273	....	....
(479) Ajuga genevensis L	May 12	483	....	....
(480) Ajuga reptans L	May 14	460	....	....
XLIII. *Globulariеæ* [*G. —; see G. 1*].				
(481) Globularia vulgaris L	May 4	397	July 7	1,253
XLIV. *Asperifoliæ* [*G. —; see G. 72*].				
(482) Cerinthe minor L	Apr. 28	357	May 29	701
(483) Echium vulgare L	June 5	786	....	....
(484) Pulmonaria officinalis L	Apr. 10	207	....	....
(485) Pulmonaria mollis Wolff	Apr. 8	207	....	....
(486) Lithospermum purpureocœruleum L	May 16	554	July 17	1,382
(487) Anchusa officinalis L	May 24	599	June 27	1,056
(488) Myosotis palustris Roth	May 30	694	....	....
(489) Symphytum officinale L	May 25	619	June 27	1,093
XLV. *Convolvulaceæ* [*G. 73*].				
(490) Calystegia sepium R. B	June 11	863	July 20	1,462
(491) Convolvulus tricolor L. (sown June 18)	Aug. 27	1,063	....	....
(492) Pharbitis hispida Choix. (sown June 18)	June 13	855	....	....
XLVI. *Polemoniaceæ* [*G. 70*].				
(493) Phlox cordata Elliot grandiflora	July 21	1,486	....	....
(494) Phlox speciosa Pursh	Aug. 14	1,890	....	....
(495) Polemonium cœruleum L	May 26	636	June 28	1,103
XLVII. *Solanaceæ* [*G. 74*].				
(496) Datura stramonium L	June 18	626	Aug. 4	1,332
(497) Hyoscyamus niger L	May 16	533	July 31	1,638
(498) Physalis alkekengi L	May 30	719	Aug. 11	1,755
(499) Solanum dulcamara L	July 17	1,437	Oct. 1	2,474
(500) Solanum nigrum L. (sown Apr. 26)	July 4	867	Aug. 31	1,744
(501) Atropa belladonna L	May 27	661	July 19	1,458

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XLVIII. *Scrophularinæ* [*G. 75*].		°*Réaum.*		°*Réaum.*
(502) Verbascum gnaphaloides M. Bieb	July 26	1,533	....	....
(503) Verbascum lychnitis L. fil. rub. lanatum floccosum	June 8	825	....	....
(504) Verbascum nigrum L. lasianthum	May 25	628	July 25	1,504
(505) Verbascum phlomoides L	June 19	1,001	Aug. 12	1,832
(506) Verbascum phœniceum L	May 16	510	July 13	1,385
(507) Verbascum speciosum L. genuinum	June 20	1,074	....	....
(508) Verbascum thapsus L	June 26	1,086	Aug. 13	1,842
(509) Scrophularia nodosa L	May 28	652	July 12	1,304
(510) Linaria genistifolia Mill	July 1	1,188	Aug. 6	1,715
(511) Linaria vulgaris Mill	July 8	1,220	Aug. 8	1,756
(512) Antirrhinum majus L	June 6	816	....	....
(513) Pentstemon barbatus Benth. robustum	July 4	1,227	Sept. 8	2,162
(514) Pentstemon digitalis Nutt	June 11	865	Sept. 5	2,158
(515) Pentstemon pubescens Poland	May 30	690	Aug. 3	1,688
(516) Digitalis lutea L	June 9	845	Aug. 1	1,653
(517) Digitalis purpurea L	June 6	772	July 20	1,482
(518) Paulownia imperialis Siebold	(518)	(518)	....	....
(519) Dodartia orientalis L	June 6	797	....	....
(520) Gratiola officinalis L	June 4	758	Aug. 8	1,730
(521) Veronica austriaca L. var. pinnatifida	May 17	504	July 12	1,312
(522) Veronica latifolia L. var. major	June 4	761	Aug. 2	1,673
(523) Veronica officinalis L	May 16	523	June 26	1,098
(524) Veronica spicata L. var. cristata	July 5	1,226	....	....
XLIX. *Acanthaceæ* [*G. 80*].				
(525) Acanthus spinosus L	June 19	985	Aug. 19	1,943
L. *Bignoniaceæ* [*G. 78*].				
(526) Catalpa syringæfolia Sims	July 3	1,193	Oct. 4	2,666
(527) Tecoma grandiflora Sweet	July 28	1,602	....	....
(528) Tecoma radicans Juss var. flammea	Aug. 8	1,746	....	....
LI. *Primulaceæ* [*G. 61*].				
(529) Primula auricula L	Mar. 15	113	....	....
(530) Cyclamen europæum L	July 18	1,437	....	....
(531) Dodecatheon meadia L	May 13	453	June 29	1,093
(532) Lysimachia nummularia L	June 21	1,021	....	....
(533) Lysimachia punctata L	June 16	926	....	....
LII. *Ebenaceæ G.* [*63*].				
(534) Diospyros lotus L. ♂	June 16	980	....	....
LIII. *Ericaceæ* [*G. 58*].				
(535) Erica carnea L	Mar. 10	80	....	....
LIV. *Umbelliferæ* [*G. 48*].				
(536) Eryngium amethystinum W. and K	July 14	1,380	Aug. 29	2,073
(537) Eryngium maritimum	July 15	1,388	Aug. 28	2,059
(538) Eryngium planum L	July 3	1,189	Aug. 5	1,645
(539) Cicuta virosa L	June 25	1,025	....	....
(540) Apium graveolens L	June 11	885	Aug. 16	1,867
(541) Petroselinum sativum Hoffm	June 20	989	Aug. 11	1,779
(542) Carum carui L	Apr. 25	338	June 12	884
(543) Sium sisarum L	July 20	1,436	....	....
(544) Bupleurum ranunculoides L. v. elatium	June 4	751	July 21	1,486

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and plant.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
LIV. *Umbelliferæ* [*G. 48*]—Continued.		° *Réaum.*		° *Réaum.*
(545) Œnanthe phellandrium Lam	June 20	984	....	....
(546) Æthusa cynapium L	July 2	1,173	Aug. 19	1,936
(547) Fœniculum vulgare Gärtn	June 27	1,114	Aug. 20	1,920
(548) Seseli campestre Besser	June 15	910	....	....
(549) Libanotis vulgaris D. C	June 27	1,113	Aug. 21	1,965
(550) Levisticum officinale Koch	June 10	858	July 17	1,395
(551) Archangelica officinalis Hoffm	June 6	769	Aug. 15	1,384
(552) Peucedanum cervarium Cass	July 17	1,417	Aug. 25	2,007
(553) Peucedanum imperatorium Endl	May 29	703	June 30	1,186
(554) Peucedanum officinale L	July 2	1,176	Aug. 13	1,797
(555) Pastinaca sativa L	July 9	1,272	Aug. 9	1,761
(556) Daucus carota L	June 18	973	Aug. 2	1,628
(557) Anthryscus cerefolium Hoffm	June 11	440	....	....
(558) Anthryscus silvestris Hoffm. var. pilosula	May 4	407	June 16	914
(559) Conium maculatum L	June 19	1,010	Aug. 2	1,688
LV. *Ampelideæ* [*G.* —; *see G. 28*].				
(560) Cissus hederacea Pers	June 24	1,057	Aug. 27	2,050
(561) Vitis vinifera L. var. alexandrina	June 7	805	Sept. 5	2,172
LVI. *Corneæ* [*G. 50*].				
(562) Cornus alba L	May 17	513	July 4	1,216
(563) Cornus mas L	Mar. 29	145	Aug. 19	1,907
(564) Cornus sanguinea L	June 1	729	Aug. 16	1,864
LVII. *Crassulaceæ* [*G. 36*].				
(565) Sedum acre L	May 31	682	....	....
(566) Sedum album L	June 25	1,072	Aug. 3	1,637
(567) Sedum latifolium Bertol	Aug. 6	1,726	Sept. 12	2,313
(568) Sedum reflexum L. var. recurvatum	June 20	1,005	Aug. 2	1,679
(569) Sedum sexangulare L	June 11	871	July 26	1,510
(570) Sedum Sieboldii Hort	Oct. 11	2,588	....	....
LVIII. *Saxifragaceæ* [*G. 35*].				
(571) Saxifraga crassifolia L. var. obovata	Apr. 19	290	....	....
(572) Saxifraga cordifolia Haw	Apr. 13	256	....	....
(573) Heuchera americana L	May 26	657	July 14	1,345
LIX. *Ribesiaceæ* [*G.* —; *see G. 35*].				
(574) Ribes alpinum L	Apr. 17	237	....	....
(575) Ribes aureum Pursh. var. sanguineum	....do...	264	June 29	1,108
(576) Ribes grossularia L	Apr. 10	226	....	....
(577) Ribes nigrum L	(577)	(577)	....	....
(578) Ribes rubrum L	Apr. 18	269	June 8	868
(579) Robsonia speciosa	May 15	469	....	....
LX. *Magnoliaceæ* [*G. 2*].				
(580) Magnolia acuminata L	(580)	(580)	....	....
(581) Liriodendron tulipifera L	(581)	(581)	....	....
LXI. *Dilleniaceæ* [*G.* —; *see G. 1*].				
(582) Actæa spicata. L	May 7	426	....	....

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plants: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
LXII. *Ranunculaceæ* [*G. 1*].		°*Réaum.*		°*Réaum.*
(583) Clematis augustifolia Jacq. lasiantha	June 3	745	....	....
(584) Clematis erecta Allion. Clematis recta L	June 4	765	....	....
(585) Clematis flammula L. var. vulgaris	July 21	1,476	....	....
(586) Clematis integrifolia L. var. elongata	May 31	701	July 18	1,405
(587) Clematis orientalis L	Aug. 24	1,988	....	....
(588) Clematis sibirica L., Atragene sibirica	Apr. 22	313	....	....
(589) Clematis virginiana L	Aug. 12	1,857	....	....
(590) Clematis vitalba L. var. bannatica	Aug. 2	1,671	....	....
(591) Atragene alpina L	May 4	398	July 14	1,329
(592) Thalictrum aquilegifolium L	May 22	582	July 30	1,598
(593) Thalictrum flavum L	July 3	1,142	....	....
(594) Thalictrum minus L	May 23	616	July 13	1,395
(595) Anemone japonica S. et Zucc	Aug. 19	1,869	Sept. 7	2,236
(596) Anemone nemorosa L	Apr. 10	224	....	....
(597) Anemone pratensis L	Apr. 6	200	May 23	606
(598) Anemone pulsatilla L	Mar. 29	151	....	....
(599) Anemone ranunculoides L	Apr. 17	275	....	....
(600) Anemone silvestris L. var. minor	May 6	413	June 14	918
(601) Anemone virginiana L. var. angustifolia	June 7	791	Aug. 13	1,825
(602) Hepatica angulosa Lam	Mar. 6	78	....	....
(603) Hepatica triloba Chaix	Mar. 10	118	May 24	647
(604) Adonis vernalis L	Apr. 16	260	....	....
(605) Ranunculus acris L. var. silvaticus	May 14	499	June 17	974
(606) Ranunculus nemorosus D. C	May 20	549	June 27	1,086
(607) Ficaria ranunculoides Roth. variegata	Apr. 4	191	....	....
(608) Caltha palustris L	Apr. 28	349	July 4	1,180
(609) Eranthis hiemalis Salisb	Feb. 27	79	May 16	527
(610) Helleborus niger L	Oct. 19	2,677	....	....
(611) Helleborus odorus W. Kit	Mar. 24	136	....	....
(612) Helleborus purpurascens W. Kit	Mar. 28	142	....	....
(613) Helleborus viridis L	Apr. 10	197	June 17	893
(614) Aquilegia atrata Koch	May 5	341	June 18	965
(615) Aquilegia atropurpurea Willd	Apr. 16	282	May 29	727
(616) Aquilegia glandulosa Mönch	May 20	562	June 28	1,133
(617) Aquilegia vulgaris L. var. rosea	May 18	511	....do...	1,094
(618) Delphinium consolida L	May 26	663	July 26	1,349
(619) Delphinium grandiflorum L	June 28	1,135	Aug. 8	1,707
(620) Delphinium intermedium Ait. var. alpinum	June 7	811	July 12	1,321
(621) Delphinium triste Fisch	June 1	723	July 1	1,176
(622) Aconitum cammarum L	July 19	1,444	Aug. 23	1,989
(623) Aconitum japonicum L	Sept. 17	2,292	....	....
(624) Aconitum lycoctonum L. var. puberulum	June 18	952	Aug. 5	1,684
(625) Aconitum napellus L	June 25	1,069	July 30	1,641
(626) Botrophis actæoides	July 1	1,141	....	....
(627) Pæonia albiflora Pallas. var. rosea	May 28	672	Aug. 3	1,678
(628) Pæonia moutan L. var. papaveracea	May 16	514	Aug. 7	1,759
(629) Pæonia officinalis Retz. var. puberula	May 18	548	Aug. 8	1,766
(630) Pæonia tenuifolia L	May 7	442	July 6	1,247
LXIII. *Berberideæ* [*G. 5*].				
(631) Leontice vesicaria Pall	Apr. 19	256	....	....
(632) Epimedium alpinum L	Apr. 26	341	....	....
(633) Berberis aquifolium Pursh. v. repens	Apr. 22	310	July 25	1,496
(634) Berberis provincialis Audib. Schrad. Lodd	May 11	472	Aug. 6	1,736

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
LXIV. *Papaveraceæ* [*G. 8*].		°*Réaum.*		°*Réaum.*
(635) Chelidonium majus L	May 5	403	June 5	785
(636) Papaver orientale L	May 25	645	June 28	1,149
(637) Papaver rhœas L (from self-sown seed)	May 19	565	June 16	946
(638) Papaver somniferum L (from self-sown seed)	June 17	994	July 10	1,219
(639) Glaucium luteum Scop	June 1	704	July 21	1,461
(640) Fumaria officinalis L	Apr. 24	316	June 8	823
LXV. *Cruciferæ* [*G. 10*].				
(641) Barbarea vulgaris R. Br	Apr. 28	342	June 30	1,144
(642) Arabis alpina L	Apr. 8	196	June 3	747
(643) Berteroa incana D. C	June 13	895	July 21	1,453
(644) Alyssum saxatile L	Apr. 19	283	June 8	802
(645) Armoracia rusticana L	May 15	512	June 27	1,103
(646) Cochlearia officinalis L	Apr. 5	214	May 31	703
(647) Iberis sempervirens L	Apr. 23	317	June 25	1,074
(648) Hesperis matronalis L	May 20	544	July 6	1,261
(649) Sisymbrium austriacum Jacq	May 6	396	June 22	1,012
(650) Erisymum crepidifolium Reichb	May 4	377	July 4	1,231
(651) Isatis tinctoria L	May 6	416	June 14	893
(652) Brassica melanosinapis Koch (sown May 2)	May 31	275	....	....
(653) Raphanus sativus L. (sown Apr. 28)	June 12	703	Aug. 5	1,376
LXVI. *Resedaceæ* [*G. 12*].				
(654) Reseda lutea L	May 20	627	....	....
(655) Reseda luteola L	May 9	437	July 17	957
LXVII. *Nymphæaceæ* [*G. 6*].				
(656) Nymphæa alba L	May 25	649	....	....
(657) Nymphæa lutea Sm	May 26	646	July 28	2,046
LXVIII. *Cistaceæ* [*G. 13*].				
(658) Helianthemum œlandicum Wahlenb	May 20	576	June 22	1,002
(659) Helianthemum vulgare Gärtn	May 23	595	....do...	1,025
LXIX. *Violarieæ* [*G. 14*].				
(660) Viola arenaria D. C	Apr. 14	244	....	....
(661) Viola hirta L. ambigua	Apr. 6	174	....	....
(662) Viola montana L	Apr. 9	182	....	....
(663) Viola odorata L	Mar. 30	157	June 2	747
(664) Viola pratensis M. et K	Apr. 26	325	June 15	919
(665) Viola tricolor L	Apr. 9	234	June 12	907
LXX. *Caryophylleæ* [*G. 15*].				
(666) Cerastium arvense L	May 7	419	June 9	824
(667) Dianthus carthusianorum L. medius	June 4	769	July 14	1,346
(668) Dianthus deltoides L	May 28	657	June 25	1,064
(669) Dianthus plumarius L. var. virens	May 22	592	June 26	1,070
(670) Gypsophila altissima L	May 28	689	June 30	1,139
(671) Gypsophila fastigata L. elatior	June 13	890	July 20	1,454
(672) Saponaria officinalis L. plena	July 16	1,399	....	....
(673) Silene inflata Smith	June 4	759	June 29	1,141
(674) Silene nutans L. albiflora	May 17	526	June 12	873
(675) Silene pseudotites Bess	May 31	716	July 7	1,276
(676) Silene saxifraga L	June 1	733	June 25	1,036
(677) Lychnis coronaria Lam	June 27	1,165	....	....
(678) Lychnis flos Jovis Lam	June 13	882	....	....
(679) Lychnis viscaria L. plena	May 18	546	June 16	890

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
LXXI. *Phytolaccaceæ* [*G. 88*].		*°Réaum.*		*°Réaum.*
(680) Phytolacca decandra L	July 12	1,325	Sept. 11	2,288
LXXII. *Malvaceæ* [*G. 20*].				
(681) Lavatera thuringiaca L	July 4	1,222	Aug. 2	1,668
(682) Althæa cannabina L	July 27	1,535	Aug. 23	1,991
(683) Althæa ficifolia Cav	July 5	1,229	Aug. 2	1,752
(684) Althæa officinalis L	July 14	1,365	Aug. 12	1,840
(685) Althæa rosea Cav	July 4	1,187	July 31	1,654
(686) Malva rotundifolia L	May 27	612	July 19	943
(687) Malva silvestris L	June 5	801	July 7	1,253
(688) Hibiscus moscheutos L	Aug. 23	1,943	....	....
(689) Hibiscus syriacus L	Aug. 11	1,803	....	....
LXXIII. *Tiliaceæ* [*G. 21*].				
(690) Tilia argentea L. fructu depressa	July 4	1,225	Sept. 9	2,138
(691) Tilia grandifolia Ehrh. latebracteata Host	June 11	871	July 29	1,607
(692) Tilia parvifolia Ehrh. ovatifolia, variegata	June 21	1,021	July 21	1,609
LXXIV. *Hypericineæ* [*G.* —].				
(693) Hypericum perforatum L	June 16	942	Aug. 23	1,988
LXXV. *Humiriaceæ* [*G.* —].				
(694) Tamarix gallica L. var. libanotica	June 3	740	....	....
LXXVI. *Acerineæ* [*G.* —; *see G. 29*].				
(695) Acer campestre var. tauricum	Apr. 30	365	Sept. 7	2,200
(696) Acer eriocarpum Michx ♂	Mar. 21	125	....	....
(697) Acer monspessulanum L	Apr. 2	292	Sept. 3	2,095
(698) Acer obtusatum Kitaib. var. neapolitanum	Apr. 10	232	Aug. 20	1,856
(699) Acer platanoides L	Apr. 14	246	Sept. 20	2,469
(700) Acer pseudoplatanus L. variegatum	May 1	373	Sept. 9	2,192
(701) Acer sanguineum Spach	Apr. 2	176	....	....
(702) Acer saccharinum L	(702)	(702)	....	....
(703) Acer striatum L	May 1	374	....	....
(704) Acer tataricum L	May 12	478	Aug. 13	1,827
(705) Negundo fraxinifolium Nuit ♂	Apr. 11	228	....	....
LXXVII. *Sapindaceæ* [*G. 29*].				
(706) Kölreuteria paniculata L	June 24	1,061	Aug. 27	2,062
(707) Æsculus flava Ait	May 11	460	....	....
(708) Æsculus hippocastanum L	May 5	409	Sept. 13	2,267
(709) Æsculus macrostachys Michx	July 10	1,300	Sept. 11	2,219
(710) Æsculus pavia L	May 9	448	....	....
LXXVIII. *Staphylaceæ* [*G.* —; *see G. 29*].				
(711) Staphylea pinnata L	May 7	428	....	....
LXXIX. *Celastrineæ* [*G. 26*].				
(712) Euonymus europæus L	May 23	601	....	....
(713) Euonymus latifolius L	May 11	466	Aug. 15	1,864
(714) Celastrus scandens L	May 24	634	Aug. 11	1,791

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
LXXX. *Rhamneæ* [*G. 27*].		°*Réaum.*		°*Réaum.*
(715) Paliurus aculeatus Lam	June 7	832	....	....
(716) Rhamnus cathartica L	(716)	(716)	....	....
(717) Rhamnus frangula L	May 20	558	July 7	1,243
(718) Ceanotus americanus L	June 30	1,195	....	....
LXXXI. *Euphorbiaceæ* [*G. 98*].				
(719) Euphorbia cyparissias L	Apr. 10	226	June 4	773
(720) Euphorbia esula L	May 5	430	....	....
(721) Euphorbia lathyris L	....	....	July 27	1,541
(722) Euphorbia pilosa L. var. tuberculata	May 2	368	June 16	953
(723) Mercurialis perennis L	Apr. 26	208	....	....
(724) Buxus sempervirens L	Apr. 16	268	....	....
LXXXII. *Juglandeæ* [*G. 101*].				
(725) Juglans cinerea L	May 5	418	....	....
(726) Juglans nigra L	May 15	503	....	....
(727) Juglans regia L. var. maxima	May 13	480	Sept. 12	2,268
(728) Juglans regia L. var. serotina	June 10	828	....	....
LXXXIII. *Anacardiaceæ* [*G. 30*].				
(729) Rhus cotinus L	May 22	593	July 6	1,270
(730) Rhus typhina L	June 12	875	....	....
LXXXIV. *Zanthoxyleæ* [*G. —; see G. 24*].				
(731) Ptelea trifoliata L	June 9	845	Aug. 21	1,979
(732) Ailanthus glandulosa Desf	June 17	956	Sept. 12	2,255
LXXXV. *Diosmeæ* [*G. —*].				
(733) Dictamnus fraxinella Pers	May 26	640	July 19	1,448
LXXXVI. *Rutaceæ* [*G. 24*].				
(734) Ruta graveolens L	June 4	765	Aug. 21	1,954
LXXXVII. *Zygophylleæ* [*G. —*].				
(735) Zygophyllum fabago L	July 4	1,221	....	....
LXXXVIII. *Geraniaceæ* [*G. 23*].				
(736) Geranium pratense L	June 8	845	July 10	1,289
(737) Geranium pyrenaicum	May 25	622	....	....
(738) Geranium sanguineum L	May 19	559	July 4	1,210
LXXXIX. *Lineæ* [*G. 22*].				
(739) Linum austriacum L	May 5	427	June 28	1,134
(740) Linum glandulosum Mönch. var. flavum	June 8	831	July 28	1,619
(741) Linum usitatissimum L. (sown Apr. 29)	June 22	688	July 24	1,179
XC. *Oxalideæ* [*G. —; see G. 23*].				
(742) Oxalis acetosella L	Apr. 8	248	....	....
(743) Oxalis stricta L	May 25	602	....	....
XCI. *Philadelpheæ* [*G. —; see G. 35*].				
(744) Philadelphus coronarius L	May 31	700	Aug. 16	1,892

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XCII. *Œnothereæ* [*G. —; see G. 42*].		°*Réaum.*		°*Réaum.*
(745) Œnothera biennis L	June 15	918	Aug. 2	1,671
(746) Œnothera pumila L	June 12	858	July 10	1,280
(747) Epilobium angustifolium L	June 29	1,113	....	....
(748) Epilobium hirsutum L	July 5	1,217	Aug. 8	1,766
XCIII. *Lythrarieæ* [*G. 41*].				
(749) Lythrum salicaria L	June 19	984	Aug. 3	1,685
(750) Lythrum virgatum L	July 16	1,344	....	....
XCIV. *Pomaceæ* [*G. —; see G. 33*].				
(751) Cydonia chinensis Thuin	May 13	492	....	....
(752) Cydonia japonica Pers	Apr. 14	268	....	....
(753) Cydonia vulgaris Pers	May 13	481	Sept. 13	2,269
(754) Pyrus americana Spr	May 19	571	Sept. 17	1,443
(755) Pyrus aria Ehrh. var. oblonga	May 11	463	Aug. 25	1,934
(756) Pyrus baccata L	(756)	(756)	....	....
(757) Pyrus chamæmespilus Lindl	May 7	420	July 16	1,360
(758) Pyrus communis L. var. sanguinea	Apr. 28	336	....	....
(759) Pyrus lanuginosa D. C	May 5	410	July 6	1,248
(760) Pyrus nivalis L	May 2	395	....	....
(761) Pyrus malus L. var. acerba	May 20	535	....	....
(762) Pyrus prunifolia Willd. xanthocarpa minor	Apr. 26	343	July 27	1,538
(763) Pyrus sorbus Gärt. var. pyriformis	May 13	491	....	....
(764) Pyrus torminalis Ehrh	....do...	489	Aug. 7	1,758
(765) Mespilus germanica L	May 20	579	Sept. 26	2,418
(766) Amelanchier canadensis F. and A. Gr. subcordata	Apr. 18	335	....	....
(767) Cotoneaster vulgaris Lindl	Apr. 22	312	June 26	1,090
(768) Cratægus monogyna Jacq	May 11	464	Aug. 12	1,842
(769) Cratægus oxyacantha L. splendens, rosea, plena	May 15	512	Aug. 19	1,933
(770) Cratægus sanguinea Pallas	May 10	475	July 27	1,603
(771) Cratægus virginica Michx	May 16	532	Aug. 12	1,840
XCV. *Rosaceæ* [*G. —*].				
(772) Rosa alba L	June 9	855	....	....
(773) Rosa alpina L. (R. canina L. var. plena)	May 19	547	July 24	1,500
(774) Rosa canina L	June 3	753	Aug. 20	1,947
(775) Rosa centifolia L	(775)	(775)	....	....
(776) Rosa damascena L	June 10	877	....	....
(777) Rosa eglanteria L	May 26	648	July 22	1,499
(778) Rosa gallica L	June 15	874	....	....
(779) Rubus fruticosus L. plenus roseus	June 27	1,103	....	....
(780) Rubus idaeus L	May 20	562	June 26	1,080
(781) Rubus odoratus L	June 17	909	....	....
(782) Fragaria collina Ehrh	May 4	410	June 6	790
(783) Fragaria vesca L	Apr. 27	345	....do...	787
(784) Potentilla alba L	Apr. 8	218	....	....
(785) Potentilla anserina L	May 12	453	....	....
(786) Potentilla argentea L. impolita	May 19	580	....	....
(787) Potentilla argentea L	May 5	393	....	....
(788) Potentilla atrosanguinea Don	June 15	896	....	....
(789) Potentilla aurea L	Apr. 29	346	....	....
(790) Potentilla chrysantha Trevir. minor	Apr. 30	366	....	....

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering. Date.	Flowering. Constant.	Ripening. Date.	Ripening. Constant.
XCV. *Rosaceæ* [*G.* —]—Continued.		° *Réaum.*		° *Réaum.*
(791) Potentilla fruticosa L	May 15	525		
(792) Potentilla hirta L	May 25	597		
(793) Potentilla pennsylvanica L	June 18	950		
(794) Potentilla pulcherrima Lehm. minuta	June 2	751		
(795) Potentilla reptans L	do	746		
(796) Potentilla rupestris L	May 9	458		
(797) Agrimonia eupatorium L. caffra	June 22	1,025	Aug. 18	1,923
(798) Agrimonia odorata Mill	July 27	1,407	Sept. 20	2,414
(799) Alchemilla montana Willd	May 4	402		
(800) Sanguisorba officinalis L. auriculata	(800)	(800)		
(801) Poterium sanguisorba L	May 27	663	June 26	1,075
(802) Waldsteinia geoides Willd	Apr. 7	216		
(803) Geum coccineum Sib	May 29	701		
(804) Geum rivale L	May 9	386	June 20	998
(805) Geum silvaticum Desrouss	May 15	529	June 18	971
(806) Geum urbanum L	May 19	554	July 6	1,243
(807) Coluria geoides R. Br	Apr. 17	229	May 28	690
(808) Kerria japonica D. C	May 15	410		
(809) Spiræa acuminata L	June 5	787		
(810) Spiræa chamaedryfolia L. var. oblongifolia	May 4	389	June 20	983
(811) Spiræa filipendula L	June 4	762	July 14	1,325
(812) Spiræa hypericifolia D. C	May 9	425	June 13	927
(813) Spiræa hypericifolia D. C. var. Plukenetii	Apr. 20	288		
(814) Spiræa opulifolia L	May 26	641	July 9	1,295
(815) Spiræa sorbifolia L	June 16	930	Aug. 8	1,741
(816) Spiræa ulmaria L. var. variegata	June 21	1,022	do	1,734
(817) Spiræa ulmifolia Scop	May 17	510	July 18	970
XCVI. *Amygdaleæ* [*G.* —].				
(818) Amygdalus communis L. variegata	Apr. 13	247	Sept. 8	2,228
(819) Amygdalus divaricata	Apr. 2	169		
(820) Amygdalus nana L	Apr. 20	293		
(821) Amygdalus persica L. plena rosea	Apr. 24	306		
(822) Prunus acida Ehrh	Apr. 23	311	June 22	1,023
(823) Prunus americana	Apr. 19	280		
(824) Prunus avium L	do	291		
(825) Prunus cerasifera Ehrh	do	290	July 13	1,340
(826) Prunus domestica L. var. Claudiana semiplena	May 4	374		
(827) Prunus mahaleb L	Apr. 29	358	June 28	1,123
(828) Prunus padus L	Apr. 28	349	June 23	1,054
(829) Prunus sibirica L	Apr. 8	233	July 11	1,330
(830) Prunus serotina Ehrh	May 24	623	Aug. 10	1,763
(831) Prunus spinosa L	Apr. 24	321	July 22	1,478
(832) Prunus virginiana L	May 4	388	June 22	1,147
XCVII. *Papilionaceæ* [*G.* —; *see G.* 32].				
(833) Lupinus polyphyllus Dougl	May 21	580	July 2	1,167
(834) Ononis natrix L (834)	June 18	965	July 25	1,525
			Aug. 9	1,810
(835) Ononis spinosa L	June 25	1,069	Aug. 5	1,710
(836) Ulex europæus L	May 17	540	July 6	1,216

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XCVII. *Papilionaceæ* [*G. —; see G. 32*]—Continued.		°*Réaum.*		°*Réaum.*
(837) Spartium junceum L	June 7	802	Aug. 13	1,842
(838) Genista tinctoria L. virgata	July 18	1,018	....	....
(839) Cytisus alpinus Mill. macrostachys	May 28	667	July 22	1,502
(840) Cytisus biflorens Host	May 3	389	June 24	1,070
(841) Cytisus elongatus M. and K	Apr. 29	362	June 25	1,087
(842) Cytisus laburnum L	May 14	497	July 29	1,598
(843) Cytisus nigricans L	June 22	994	Aug. 15	1,831
(844) Anthyllis montana L	May 17	555	July 19	1,479
(845) Medicago sativa L	June 8	827	Aug. 5	1,719
(846) Melilotus officinalis L	June 11	855	Aug. 7	1,661
(847) Trifolium alpestre L	June 4	766	July 14	1,389
(848) Trifolium montanum L	May 16	548	June 24	1,100
(849) Trifolium pratense L	May 30	687	June 25	1,075
(850) Trifolium repens L	June 1	670	....	....
(851) Dorycnium herbaceum Willd	June 16	957	July 27	1,607
(852) Tetragonolobus siliquosus Roth	May 21	593	July 2	1,153
(853) Amorpha fruiticosa L	June 7	805	Sept. 16	2,305
(854) Psoralea acaulis Steven	June 15	900	July 25	1,523
(855) Glycyrrhiza glabra L	June 26	1,098	Aug. 13	1,363
(856) Galega officinalis L	June 16	951	July 30	1,644
(857) Robinia hispida L	May 21	588	....	....
(858) Robinia pseudoacacia L. var. inermis	May 30	683	....	....
(859) Robinia viscosa L	May 31	718	Aug. 27	2,064
(860) Caragana arborescens Lam	May 3	391	July 14	1,326
(861) Caragana frutescens L. silvatica	May 7	430	June 26	1,027
(862) Colutea arborescens	May 27	649	July 14	1,361
(863) Astragalus cicer L	June 6	808	July 12	1,339
(864) Astragalus galegiformis Sibth	May 30	697	July 8	1,256
(865) Astragalus illyricus Bernh	May 4	403	....	....
(866) Astragalus maximus Willd	June 6	813	July 20	1,478
(867) Astragalus onobrychis L. microphyllus	June 5	787	July 28	1,613
(868) Pisum sativum Poir (sown May 2)	July 2	782	July 30	1,256
(869) Ervum lens L. (sown May 2)	June 25	688	July 26	1,169
(870) Lathyrus latifolius L	June 12	893	Aug. 2	1,674
(871) Lathyrus silvestris L. var. ensifolius	June 8	814	....	....
(872) Orobus albus L. rubescens	May 3	407	June 22	1,021
(873) Orobus niger L	May 27	669	July 21	1,481
(874) Orobus roseus Ledeb	May 25	646	....	....
(875) Orobus vernus L. var. flaccidus	Apr. 29	291	June 7	824
(876) Orobus versicolor Gmel	May 9	444	....	....
(877) Coronilla emerus L	May 10	454	July 12	1,364
(878) Coronilla minima L	May 5	443	July 7	1,269
(879) Coronilla montana L	May 27	664	Aug. 1	1,656
(880) Coronilla varia L (880)	June 12	869	{July 26 {Aug. 15	1,552 1,839
(881) Onobrychis satia L	May 22	634	June 29	1,138
(882) Phaseolus vulgaris Savi. (sown May 2)	July 2	778	Aug. 8	1,387
(883) Cladrastis tinctoria Raf	June 4	765	....	....
(884) Styphnolobium japonicum Schott	Aug. 4	1,672	....	....

Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
XCVII. *Papilionaceæ* [*G.—; see G. 32*]—Continued.		°*Réaum.*		°*Réaum.*
(885) Cercis canadensis L.	May 8	449	....	....
(886) Cercis siliquastrum L.	May 16	511	Oct. 5	2,430
(887) Gleditschia triacanthos L. inermis	June 5	756	Sept. 20	2,332
(888) Gymnocladus canadensis Lam.	June 4	763	....	....
(889) Cassia marylandica L.	July —	1,631	....	....

54. Very rarely blossoms.
57. The fruit ripens during the following season.
168 and 175. Did not bloom during the ten years.
179 and 189. Tree too young to blossom.
203. The concealed blossoms can not be accurately observed.
270 and 271. The dates of blossoming are too variable to allow of determining a thermal constant.
304. These figures obtain for moist years, but for dry years we have September 9 and 2237, respectively.
308. Blossomed only once during these ten years.
518. The blossoming of the tree is not easy to observe.
577. The tree died in 1855.
580 and 581. Too young to blossom.
702 and 775. Did not blossom.
716. Blossomed only once and died in 1857.
756. Did not blossom and died in 1856.
800. Dates are too variable to allow determining a thermal constant.
834 and 880. The dates when the hull hardens and colors and when it springs open, allowing the fruit to fall, are both given.

LINSSER.

The most elaborate and, I believe, the most important investigation into the relation between plant life and climate is that published by Karl Linsser in a first memoir (St. Petersburg, 1867) and in a second memoir of 1869. My personal association with him during 1865 and 1866 greatly stimulated my own early interest in the subject. The conclusions arrived at by Linsser are based upon the study of all available European observations. His knowledge of physics and skill in numerical computations as the chief of the computing division of the Imperial Astronomical Observatory at Poulkova has given his results a precision based on the well-established principles of probabilities and a clearness of interpretation that specially commend them to the physiological botanist. Linsser states that the principal hypotheses that had up to his time been framed as to the form of the connection between the phenomena of temperature and of phenology are the following three:

(1) That for the same plant the same stage of vegetation occurs from year to year on the attainment of the same mean daily temperature.

(2) That the same stage of vegetation is attained when in the course of any year the sum total of the mean daily temperatures above freezing attains the same value.

(3) That the same stage of vegetation is attained when in the course of any year the sum of the squares of these positive temperatures attains a certain constant value.

The first of these hypotheses has, he states, long since been given up as of insufficient accuracy not only for any given station, but still more when we consider the temperatures belonging to a given stage of vegetation of the same plant in localities that differ much in latitude or longitude.

The third hypothesis is that which was favored by Quetelet, and the second is that which had for a hundred years been generally adopted by botanists. Both of these two latter hypotheses were most thoroughly investigated by Erman in his memoir, published in 1845 and 1849.[a]

Erman demonstrates that both these hypotheses are unsatisfactory, but Linsser proposes to reinvestigate the question on the basis of a much larger collection of material, both phenological and meteorological.

The first step in Linsser's investigation consists in finding a method of computing the sums of the temperatures or the sums of the squares of the temperatures above freezing when the average temperature of any day of the year is expressed by the so-called sine and cosine formula of Bessel. He computes the coefficients of Bessel's formula, and therefore knows the equations that express the mean daily temperature for any day in the year and for each of his stations of observations.[b]

The summation of the squares of the mean daily temperatures was computed by Linsser by the method known as mechanical quadratures. The following table illustrates his results for seven groups of

[a] I very much regret that I have not been able to examine these memoirs, which are published in the Archiv für Wissenschaftliche Kentnisse Russland, Vols. IV and VIII.—C. A.

[b] A similar computation had been made by Erman, but for the benefit of those who may in the future have to go through similar labors I would suggest that it is not more laborious and is certainly more perspicuous to compute the actual daily temperature for every fourth day of the year, beginning with January 0, and in the adjoining column make up the continuous summations. The difference between the sums for any two dates is then the total mean daily temperature to which the plant has been subjected.—C. A.

plants that were observed at Brussels and at Poulkova, which is 12 miles south of St. Petersburg:

Group of plants.	Date of blossoming.		Sums for Brussels.		Sums for Poulkova.	
	Brussels.	Poulkova.	Temperature.	Squares of temperature.	Temperature.	Squares of temperature.
	Days.	*Days.*	° *C.*	° *C.*	° *C.*	° *C.*
1	85.4	137.4	247	1,022	180	1,145
2	98.9	149.0	347	1,751	300	2,394
3	119.9	161.4	550	3,730	458	4,411
4	138.0	169.5	773	6,497	575	6,100
5	160.4	184.2	1,102	11,506	807	9,776
6	181.6	190.5	1,471	17,764	912	11,527
7	222.0	223.0	2,219	31,615	1,460	20,700

In taking these sums, which all relate to positive temperatures on the centigrade thermometer only, Linsser begins with April 8 at Poulkova, because on that date the gradually rising daily temperatures pass through the freezing point. It would have made no difference if he had begun with January 1, or December 1, or with the date of lowest mean temperature, which would be about the middle of January. On the other hand, for Brussels his sums begin with January 15, which is the date at which the lowest mean daily temperature occurs, which temperature is about +2.5° C., so that if he had begun with January 1 there would have been a constant slight addition to all the numbers in that column. The dates of blossoming are given in days counting consecutively from the 1st of January, and may be converted into the days of the month or vice versa by the following table:

Date.	Day of the year.		Date.	Day of the year.	
	Ordinary.	Leap.		Ordinary.	Leap.
January 1	1	1	August 1	213	214
February 1	32	32	September 1	244	245
March 1	60	61	October 1	274	275
April 1	91	92	November 1	305	306
May 1	121	122	December 1	335	336
June 1	152	153	January 1	366	367
July 1	182	183			

If we take the difference between the sums of the temperatures for the first and seventh groups of plants in the preceding table we obtain for Brussels 1,972° C., and for Poulkova 1,280° C., or a difference of about 700° C., which corresponds to about forty days at Poulkova, so that we must immediately conclude that the same stages of develop-

ment are attained by means of very different sum totals of temperatures at Poulkova and Brussels.

But possibly we should have taken the initial point of vegetation at some other temperature than 0° C. In order to test this point Linsser performs the computations of the sums of temperatures above 1°, 2°, 3°, 4°, 5°, and 6° C., respectively. His result for 6° C. is as follows:

Group.	Brussels.	Poulkova.	Group.	Brussels.	Poulkova.
	°C.	°C.		°C.	°C.
1	1	21	5	412	368
2	20	72	6	995	435
3	97	155	7	1,154	788
4	212	224			

None of these successive hypotheses as to the initial temperature for vegetation gives a uniform constant any more than does the original hypothesis of 0° C.

A similar study of the sums of the squares demonstrates a similar result, so that in general at different places the same phase of development of vegetation requires different mean daily temperatures, different sums of temperatures, and different sums of the squares of temperatures, and there is no zero point that can be adopted that will make these sums equal.

Linsser then shows that, notwithstanding this result, there still is a thermal law concealed in the above figures. For evidently the sums for Brussels and Poulkova go on steadily increasing through the whole period of vegetation, and at any stage the numbers are very nearly in the same proportion, and that proportion is very nearly the same as the proportion between the sum total for the year at the two places. These annual sums total are for Brussels 3,687, and for St. Petersburg 2,253. If now the numbers in the fourth and sixth columns of the table on page 213 be divided by these annual sums, respectively, we obtain the following:

Ratio of the individual sums to the total annual sums of temperature above 0° C.

Group of plants.	Brussels.	Poulkova.	Group of plants.	Brussels.	Poulkova.
1	0.07	0.08	5	0.30	0.36
2	.09	.13	6	.40	.40
3	.15	.20	7	.60	.65
4	.21	.26			

The agreement of these numbers is quite close enough to justify the conclusion that in two different localities the sums of positive daily temperatures for the same phase of vegetation is proportional to the

annual sum total of all positive temperatures for the respective localities. The discrepancies between the above figures also show that a systematic influence is at work to slightly increase the ratio for the northern stations, since the ratios for Poulkova are appreciably larger than those for Brussels. This influence, as Linsser suggests, is probably to be found in the fact that a larger proportion of heat is consumed at the northern stations in melting the snow without changing the temperature, which heat is therefore lost to the growth of plants.

The law thus discovered by Linsser is tested by him for each of the 15 phenological stations studied in his first memoir, and not only does the ratio appear the same for each phase, but the slight increase as the latitudes increase is also confirmed, or, in other words, the ratio increases slightly as the annual sum total of positive temperatures diminishes, the increase being nothing for the first group of plants that blossom early in the spring and about 0.1 for the seventh group of plants that blossom in midsummer per diminution of 2,000° C. in the annual sums.

Linsser also states this law in the following form, in which it has a more popular expression:

Every individual plant possesses the ability to regulate its vital activity as demanded by the total heat available in its dwelling place and according to the habit inherited from its ancestors, so that individuals of the same species living in different places arrive at the same phase of development by utilizing the same proportions of the total heat to which they are accustomed. The vegetable world, so far as we consider its vital phenomena, is indifferent to temperatures below the freezing point.

The preceding principle has been deduced primarily from the study of one phase, viz, the blossoming; but a study of the figures of the other phases gives a similar result, so that the method by which heat exercises its influence on plants is the same for all stages of development.

The phase recorded as "the falling of the leaves," which indicates the approach of the winter sleep of perennial plants, is the only one that to a high degree depends upon the actual temperature at that date.

Apparently the statement, frequently assumed as a general law, that the dates of leafing and of the falling of the leaf at the same place have the same temperatures is only approximately true for a single plant and a special locality, as, for instance, France and central Europe, and does not hold good for the same plant for northern or southern Europe.

Linsser's law has a most important application to the natural dissemination of seeds and the acclimatization of plants. When we, at a given place, from year to year, see the same cycle of vegetation recur without changing the behavior of the plant with reference to the annual sum total of heat, we must conclude that the ability to develop itself in proportion to the total heat is transmitted from each

mother plant down to the seed produced by it. Therefore in every kernel of seed there is concealed the whole relation between the development of the plant and the total heat of the locality where it was produced. Two seeds of the same species, one of which comes from a mother plant that has lived under the influence of an annual total heat of M, but the other of which comes from another mother plant that has lived under a total annual heat of N, possess powers of development, or a sensitiveness to equal temperature influences, that are inversely proportional to the sums M and N; or, in other words, the rate of development is equal to the sum of the effective temperatures divided by the normal values of the total annual sums for the mother plant.

Applying this law to seeds that are artificially transported from their homes to other places having different climates as to temperature we are enabled to predict approximately what their behavior will be. Thus Von Baer observed that cress seeds that had been raised in St. Petersburg (lat. 60°) and transported to Matotschkin-Schar (lat. 73°) developed in July at only one-third the rate that they did in St. Petersburg in the month of May. Now the annual sum of positive temperatures for St. Petersburg is 2,253° C., and the average temperature of the month of May in St. Petersburg is 11.2°, while that of the month of July at Matotschkin-Schar is 4.4°. Therefore the rates of development per day of the same seed at these two places will be in the ratio of 11.2 to 4.4, or 2.6 to 1. Again, for cress seeds raised at Matotschkin-Schar, where the annual total heat is 330° C., the rate of development will in general be $\frac{2253}{330}$, or 6.8 times more rapid than the development of seeds brought from St. Petersburg. Vice versa, seeds carried from Matotschkin-Schar to St. Petersburg the rate of development will be 6.8 times more rapid than for those that are native to the latter climate.

Linsser was thus able to enunciate the first step in the rational explanation of a phenomenon with which agriculturists had long been familiar—viz, that the seeds raised in northern zones retain the power of rapid development, so that when sown in southern regions they grow more rapidly and ripen earlier and give a richer harvest than those that are sown in their native warm locality. Similarly, seeds of mountain plants, when carried by rivers into the warmer plains of the lowlands, develop plants whose blossoms antedate the spring blossoms of the plants native to the lowlands.[a] We may thus accept the general statement that plants or seeds transported to colder countries reach a given stage of vegetation later than the

[a]A beautiful illustration of this law is found in the abnormal early flowering of seeds brought from the cold uplands and lodging on High Island, on the Potomac, about 5 miles above Washington, D. C.

native plants, but when transported to warmer regions they blossom and ripen earlier. Thus in 1859 Schuebeler sowed 6-rowed barley that had been raised in Alten (lat. 70° N.), where it required only nine weeks to ripen, in Christiania (lat. 60° N.), where it ripened in eight weeks. In the same year some of the same barley was carried from Breslau, where it required nine and a half weeks, to Christiania, where it ripened in twelve to fourteen weeks. Linsser arranged these experiences as shown in the following table, in which he assumes that both at Alten and at Christiania the barley is sown when the mean daily temperature is about 8° C.

Barley raised at—	Date of sowing.	Date of ripening.	Interval.	Sums of temperature.
			Weeks.	°*C.*
Alten and sown at Alten	June 14	Aug. 16	9	700
Alten and sown at Christiania	May 5	June 29	8	....
Christiana and sown at Christiana	....do....	Aug. 1-9	13	1,400

The annual sum totals of heat are 1,300 in Alten and 2,600 in Christiania. Therefore we see that the heat required by seed acclimatized at Alten (700) is to that required by seed acclimatized at Christiania (1,400) in the same ratio as the annual sum totals.

It can also be shown that barley acclimatized at Christiania and transported directly to Alten can not ripen in the latter place, since the 1,400° C. required by it at Christiania are not received at Alten. It is only by gradual progressive acclimatization at numerous intermediate places that the plant has been enabled to adapt itself to successively smaller sum totals of heat. In continuation of this process the barley that is now accustomed to ripen at Alten can be used to pioneer the further northward progress of its species. The attempt to transport barley from Denmark to Iceland has thus far failed, but doubtless barley from Alten would succeed. Barley cultivated in the Caucasus at an elevation of 7,000 feet and transported to St. Petersburg should, according to Linsser's computation, experience an acceleration, so far as climate is concerned, as though it were coming to a warmer climate, but this acceleration may be more than counterbalanced by the differences in the nature of the two species of plants, as it is well known that the Turkish oats (*Avena orientalis*) require more time to ripen than the ordinary oats of northern Europe; the variations in times required by different kinds of oats, barley, and wheat, and even winter rye, are oftentimes larger than the variations due to differences of climate. But such variations, as observed in plants that are only partially acclimatized, will disappear after a few generations if the plant has the power of adapting its internal organ-

ization to a new climate. The geographical limits of any species, in latitude, so far as these limits depend upon temperature alone, are those points at which a certain sum of positive temperatures can be attained between the first and the last killing frost. The northern and southern boundary lines of such a limiting area are the curves corresponding to two very different sums total of positive temperatures, the northern limit having a smaller sum and the southern limit a larger, beyond either of which the plant is unable to modify its internal organization so as to properly utilize the respective prevailing small or large quantity of heat.

Linsser notes that different plants, especially those that blossom early in the year, show a strong tendency in certain years to blossom a second time, and he finds that when the excess of the total heat in a favorable year exceeds the normal annual total by a quantity equal to that ordinarily required for the first blossom (and this can easily happen on account of the small sum required for the early spring blossom) then the plant produces a second blossom.[a]

In regard to the effect of daylight as such, Linsser says the opinion has been expressed that possibly the duration of the daylight, which, during the growing period, increases as we go northward, must compensate for the diminishing sum total of heat; but his figures show nothing of this influence, since the discrepancies or departures between his observed and computed figures have altogether the character of accidental errors. In fact, his law of the constant quotient or percentage of heat implies that the plant does not need any compensation as the heat is diminished, but directly adapts its cycle of operations to the diminished sum and transmits this power to all further generations. In addition to this, however, since the importance of light to the plant is proven, it is necessary to remember that with the increasing duration of the day as we go northward there is a steady diminution in the intensity of the daylight because

[a] Ought we not to infer from this that after a perennial plant has received sufficient heat to blossom and eventually to ripen its fruit it then at once begins to repeat this cycle of processes, and is ordinarily only delayed by the cold of winter? If this is true, it must be considered that with the warm weather of spring the plant takes up these vital processes at the point where they were left in the autumn. Therefore, in such cases, our sums total of temperature, moisture, etc., should all begin to be counted with the ripening of the fruit, or the fall of the leaf, and not merely with the opening of vegetation in the spring.—C. A.

the sun's altitude diminishes. This Linsser shows in the following table.[a]

Date.	Maximum duration of sunshine.		Altitude of sun at noon.		Relative quantity of heat received by the ground in 1 day under an atmosphere whose transparency is 0.70.			
	Venice (lat. 45.4° N.).	St. Petersburg (lat. 60° N.).	Venice (lat. 45.4° N.).	St. Petersburg (lat. 60° N.).	Lat. 40° N.	Lat. 50° N.	Lat. 60° N.	Lat. 70° N.
	Hours.	*Hours.*	*Degrees.*	*Degrees.*				
January 16	9.0	6.8	23.7	9.0	150	70	15	0
February 15	10.3	9.2	31.5	16.9	210	155	65	14
March 16	11.9	11.8	42.8	28.2	400	295	190	95
April 15	13.5	14.5	54.3	39.7	520	450	360	255
May 16	14.8	17.2	63.6	49.1	615	570	505	425
June 15	15.6	18.8	67.8	53.4	650	625	570	505
July 16	15.3	18.1	66.0	51.5	630	585	525	450
August 16	14.1	15.6	58.4	43.9	550	480	395	295
September 15	12.6	13.0	47.7	33.2	430	335	230	125
October 16	10.9	10.2	35.8	21.2	280	185	90	25
November 15	9.5	7.6	26.2	11.6	180	85	20	0
December 16	8.7	6.0	21.3	6.7	135	50	2	0

In reference to the first part of this table Linsser remarks that the intensity of the light of the sun varies as the sine of the angular altitude of the sun, so that from the maximum altitude on any day we get an approximate idea of the influence of sunshine; and we see also that the farther north we go the longer duration of the sunshine is partly counterbalanced by the diminishing intensity of its influence.[b]

Linsser remarks that the theory of compensation between duration of the day and intensity of sunshine may also be tested by considering the effect of ascending a mountain, where there is no increase of duration but a great increase in the intensity, of sunshine. If the rapid development of the plants on the mountains is due to the increase in the intensity of the light, then how can the diminution of intensity in northern regions bring about the rapid development that is demonstrated in the experiments of Von Baer and Schuebeler and Ruprecht which are quoted and analyzed in the following paragraphs?

[a] To which I have added three columns of relative intensity of the total heat received in twenty-four hours on each date, as interpolated from Angot's tables, for a coefficient of transparency equal to 0.70.—C. A.

[b] The exact figures that give the relative sum total of the direct sunshine and the diffuse daylight for various latitudes and solar altitudes for clear and cloudless days have been published by Marie Davy, Angot, Wiener, and others. The figures that I have given in the last part of the above tables from Angot show still more clearly to what extent the effect of sunshine diminishes as we approach the pole, but how surprisingly powerful are the consecutive twenty-four hours of sunshine on June 15 within the Arctic Circle.—C. A.

In his second memoir Linsser (1869) begins by showing that many well-recognized facts have been found which harmonize with the conclusions at which he had previously arrived. Thus, in the first and second halves of the eighteenth century the northern limit of the cultivation of grain had not passed beyond latitude 60° 30′ N., and many unsuccessful attempts had been made to ripen the grains in more northern regions; but in 1829 Erman found a small successful beginning going on at Yakutsk, and since then it has spread in all directions and has extended to barley, oats, rye, and wheat. Similarly in Lapland the cultivation of grain succeeded only for a long time in the southern regions, but now it extends to the north and even among the mountains. In Lapland this cultivation succeeded only when the seed was brought from near by, not from a distance, and Von Baer says that it was commonly said that the grain had acclimatized itself, or, as he expresses it, "It seems to me that gradually a quick-ripening variety or 'sport' has developed that is not injured by the early frosts of summer nights."

F. C. Schübeler (1862) in his memoir on the cultivated plants of Norway states that in 1852 the seed of yellow maize brought to Norway from Hohenheim, near Stuttgart, was sown on the 26th of May and reaped one hundred and twenty days later, but after continued annual cultivations, in which every harvest came a little earlier than its predecessor, Schübeler, in 1857, sowed the seed on May 25 and harvested it in ninety days, while the seed of the same variety brought fresh from Breslau and sowed on the same date ripened only after one hundred and twenty-two days. Even Kalm had remarked that maize when transported from a southern to a northern latitude gradually overcomes the difficulty of ripening and eventually gives a nearly constant variety of grain.

Morren, in the Belgique Horticole (1859–60), says the principal problem to be resolved in Norway in the amelioration of its agriculture is the introduction of new varieties and the development of precocity. This precocity increases year by year, as if the plant could not all of a sudden obey the new climatic influences under which it had been brought. Plants cultivated many years in succession under a northern climate when transported to a southern climate preserve something of their former rate of development and are more precocious than plants of the same species that have remained in their first situation. Just as wheat carried from Germany northward into the Baltic Provinces of Russia fails to ripen its grain, so grain carried from the valleys up to the highlands in Switzerland fails to ripen.

Bastian quotes an old English author who says that in the acclimatization of plants the graduation of the process is the principal necessity, and that a sudden acclimatization in a new home is impossible, so that a plant gradually learns to live in a climate in which

its mother plant was sickly and its grandmother would have died at once. It was in recognition of this view that in the eighteenth century the botanical garden at Teneriffe was established (the so-called acclimatization garden at Durasno and the Colegan Garden at Orotava, at an altitude of 1,040 feet) in order to furnish a temporary resting place for tropical plants that they might accustom themselves to a cooler climate preparatory to their cultivation in southern Europe. According to Döllen, the same principle is applied in the acclimatization garden at Algiers to tropical African plants before their transportation into southern France.

As the guiding thought of his second memoir, Linsser now remarks that we must divide the vegetable phenomena of the world into two divisions, viz, those in which temperature controls the annually recurring cycle of phases, as is the case in the Temperate Zone, and those in which moisture controls, as in the Tropical Zone. Thus, on the grassy plains of South America, where the year is divided into a dry and a wet season, the entire course of vegetation depends upon the latter; the hottest and driest season exerts upon the vegetable life an influence like that of the northern winter, bringing, namely, rest and even death. Such a contrast is even found at Madeira, where, according to Heer, the weeds of northern Europe begin to vegetate in the fall after the dry summer months of trade winds and when the first rains fall, whereas in the hottest summer time all these weeds slumber or die, as with us in winter. In the steppes of Orenburg, Russia, when the sun melts the snow in April, it starts the first sprouts and the blossoms, and by the beginning of May the vegetation of the steppes has attained its highest brilliancy, being distinguished by the great number of many-colored tulips, as has been so often described by travelers; but this beauty passes by with remarkable rapidity, and when in June the dry, hot summer of the steppes begins, all the verdure is dry and dead, and in place of the blossoms there are seen only the dry, empty hulls; so that the whole life of the plants on the steppes is condensed into the short space of eight weeks.

We thus see that for large portions of the earth the heat as such ceases to be the principal regulator of plant life, and moisture becomes the controlling influence.

It is evident that the life of plants depends upon both temperature and moisture. In situations where there is always sufficient moisture the influence that decides whether or not a plant shall develop is the heat; but in regions where there is always sufficient heat that deciding influence is moisture. Therefore Linsser proposes in his second memoir to first state the influence of heat on vegetable phenomena more precisely than he had previously done, and then to develop the influence of moisture.

Linsser's second study is based upon a much larger mass of phenological observations than that previously used by him, and, in fact, more than has ever been used by any other investigator of this subject. The accompanying table gives for each of his stations the initial and final dates when the normal mean daily temperature is 0° C., or the date when the minimum of the year occurs if that minimum is above 0° C.; these are the limiting dates between which the summation of temperature is made according to Linsser's method. The sums total of positive temperatures for the whole year are given in the third column in centigrade degrees.

Station.	Initial date.	Final date.	Annual sums of positive temperatures.	Linsser's zones.
			°C.	
Pessan	Jan. 15	Dec. 31	5,226	A
Parma	Jan. 17	...do...	4,797	B
Venice	Jan. 11	...do...	4,669	A
Dijon	Jan. 5	...do...	4,251	A
Heidelberg	Jan. 14	...do...	8,933	A
Paris	Jan. 13	...do...	3,929	A
Namur	...do...	...do...	3,865	A
Ghent	Jan. 12	...do...	3,815	A
Kischineff	Mar. 2	Dec. 8	3,799	B
Vienna	Feb. 8	Dec. 18	3,757	B
Ostend	Jan. 14	Dec. 31	3,737	A
Brussels	Jan. 16	...do...	3,687	A
Prague	Feb. 16	Dec. 16	3,582	B
Swaffham	Jan. 20	Dec. 31	3,520	A
Brunswick	Feb. 8	...do...	3,433	A
Sarepta	Mar. 27	Nov. 12	3,271	B
Stavelot	Jan. 20	Dec. 31	3,151	A
Munich	Feb. 14	Dec. 16	3,125	A
Tubingen	Feb. 9	Dec. 1	3,125	A
Stettin	Feb. 18	Dec. 18	3,115	A
Kief	Mar. 16	Nov. 21	3,035	B
Kreuzburg	Feb. 28	Dec. 16	3,018	A
Gorlitz	Feb. 19	Dec. 6	2,975	A
Breslau	Mar. 2	...do...	2,953	B
Orel	Apr. 1	Nov. 13	2,807	A
Moscow	Apr. 4	Nov. 4	2,631	A
Riga	Mar. 26	Nov. 22	2,574	A
Christiania	...do...	Nov. 11	2,389	A
Abo	Apr. 3	Nov. 13	2,303	A
St. Petersburg	Apr. 8	Nov. 9	2,253	A
Carlo	Apr. 19	Oct. 30	1,898	A

A plant has access to water by two methods—through its roots it absorbs the water in the soil, whereas its leaves come in contact with the vapor and the rain in the atmosphere; but Linsser considers that the relation of the plant to the water in the soil is the important feature that decides as to the development of the peren-

nial plants of temperate regions, which are those considered in his second memoir. So he leaves the study of atmospheric vapor and plant life to the future, while confining himself at present to the relation between rainfall and the periodic phenomena of vegetation.

It is not necessary to reproduce the tables of normal monthly rainfall given by Linsser for each of his stations, and generally based upon many years of observations. Of course, these numbers expressing the local rainfalls are, as is well known, less directly applicable to a neighboring locality than are the mean monthly temperatures, and they must be used with correspondingly less confidence.

The constant fractional part of the annual sum total of heat, as previously established by Linsser, afforded him a valuable suggestion or a working hypothesis as to the relation between the life of the plant and other factors, such as sunshine, rainfall, nutrition, and in fact every factor that influences the life of the plant. If, namely, a plant utilizes one-tenth of its annual cycle of heat in order to bring it to the leafing stage, why may it not also require one-tenth of its annual cycle of rain or sunshine or some similar constant fractional part? Now, in the development of a plant there is necessary, first, the material, viz, rainfall, or irrigation water with the nutrition contained therein, and on the other hand one or more forces, such as sunshine and heat, by the help of which the plant can utilize that material in its process of assimilation. The different phases of the development of the plant, such as the appearance of the blossoms and the ripening of the fruit, are work accomplished; in this work the water supplies the principal material, while the heat, says Linsser, plays the rôle of the principal force; but the work of the plant—that is to say, its progressive development—will only be in proportion to the force, so long as the latter finds a sufficient quantity of material present to insure the complete utilization of the force. Evidently a force that is competent to convert a certain quantity of material to the use of the plant will only be half utilized if only half of this quantity of material is present. In other words, the development of the plant goes on in proportion to the quantity of heat only so long as the plant has at its disposal the maximum quantity of material that can be worked over by this heat.

Therefore any further investigations as to the relation of the life of a plant to its external factors must necessarily consider the distribution of material with reference to the distribution of heat. In our present case it is the distribution of the quantity of rain with reference to the heat, and if such relative distribution is not considered then its omission is only permissible under the assumption that during the whole period of vegetation the material necessary to the growth of the plant is always present in such quantity that at any

moment the force then acting can be completely utilized. This assumption as to rainfall is actually fulfilled over by far the largest part of the European area hitherto studied by Linsser.

Of course, we can not speak of absolute quantities of heat or nourishing material. We have to do only with their relative distribution during the period of vegetation—that it to say, with the ratio of the quantity of material (f) to the quantity of heat (w). If we consider that the quantity of material that a definite quantity of heat is able to work up for the use of the plant is directly proportional to this quantity of heat, then the ratio f/w will have for each plant and phase a certain definite value that may be called the most favorable ratio and for which value the material on hand is completely used up by the heat or active force that is present. If the material that is present is not sufficient for the heat, then f/w is smaller than this most favorable value, and in this case the material is completely used up; but a portion of this heat remains unused and wasted. If, on the other hand, the heat is not sufficient to use up all the material, then f/w is too large and the heat is completely used, but a portion of the material is wasted.

The fractional portion of the annual sum total of heat that is needed to bring a plant up to any stage of vegetation is by Linsser called the "physiological constant" for that phase and plant, and is constant wherever the plant is acclimatized. The ratio f/w, as compiled by him month by month for each of his stations, is a local climatic constant, which is large when the climate is favorable to the growth of the plant—that is to say, when there is abundance of rain—but is small when the climate is more or less unfavorable to the plant—that is to say, when the summer rains are deficient.

The vegetation of the whole world is, according to Linsser's views, to be divided into zones (A, B, C, D, E, F), according to the annual distribution of the monthly ratios f/w. Thus in the highest latitudes (Linsser's zone A) and in the greater part of the European region covered by Linsser's researches, there is during the entire year a deficiency of heat, but a sufficiency of moisture and of material to employ all the heat force that is available. In the Steppes of Russia, however, there is a deficiency of moisture during the summer and autumn, and the fraction f/w becomes quite small for the zone B. The other localities that have a wet and a dry period annually may be divided into three classes, viz, C, where the drought comes during the months of July and December; D, where the drought comes during the months of January and June, or E, where there are two annual droughts, January to March and June to August. This latter arrangement is shown in Madeira in the vegetation of certain kinds of apples. Finally, we may have in zone F a perpetual abundance

of both heat and moisture, in which case all annual periodicity disappears and the plant goes through its cycle of vegetation independent of the months of the year, as in the warm and rainy regions of Java.

As before said, the absolute value of the ratio f/w need not be considered at present, and in fact it changes with the units of time, of temperature, or rainfall, etc. Linsser divides the depth of the monthly rainfall, expressed in Paris or French lines, by the average temperatures of the respective months expressed in degrees Centigrade.

In order to ascertain which of his European stations lies in the zone A and which in the zone B it is necessary to adopt some limiting value for the ratio f/w, and to this end Linsser examines these ratios in connection with the phenomena of plant life, adopting the principle that as two plants from different places, accustomed to different quantities of heat, behave differently when they both receive the same quantity of heat, so also two plants from places having different distributions of rain will behave differently and arrive at the same phase at different times when they are brought into the same place or under the same local climatic influences as to moisture and temperature.

In order to decide as to the limiting value Linsser studies the ratios for the hottest months of the year, which all relate to the ripening phases of vegetation, and finds that for the units of measure adopted by him the value of ratio f/w, that represents approximately a dividing line between the stations that have an abundance of rain in summer relative to the summer heat and those that have little rain relative to the heat, is 1.2. I have indicated in the preceding table by the letters A and B the stations that have $f/w>1.2$ and $f/w<1.2$, and which Linsser puts into his zones of abundant and scanty summer rains, respectively.

I give in the following table some of the more striking and permanently important results of Linsser's computations. His original work, based on about 30,000 observations, gives for each of his 31 stations and for 118 species of plants and for each of the three phases—leafing, blossoming, and ripening—the ordinary phenological constant or sum total of mean daily temperatures above 0° C., and also his own physiological constant, which is the ratio of this sum total to the annual sum total for the station. In the following summary I give the physiological constant as it results from the average of all the individual stations in the zone A; but for the sake of quicker comparison between the results for zones A and B the summary gives not the physiological constant for B, but its departure or difference

from that of zone A. For example, for *Acer campestre* the constant in zone A for leafing is 0.131, but for zone B it is less than that by 0.039, and would therefore be 0.092.

Tabular summary of Linsser's results.

Orders, suborders, and species.	Physiological constants for zone A.			Departures of physiological constants for zone B from those of zone A.		
	Leafing.	Blooming.	Ripening.	Leafing.	Blooming.	Ripening.
Sapindaceæ (Acerineæ):						
Acer campestre	0.131	0.170	0.803	−0.039	−0.072	−0.098
Acer platanoides	.100	.105	.875	− .020	− .019	− .313
Acer pseudoplatanus	.132	.161	.808	− .029	− .067	− .110
Acer tataricum	.132	.225	.752	....	− .053	− .132
Sapindeæ:						
Aesculus hippocastanum	.107	.187	.821	− .030	− .054	− .064
Aesculus lutea	.114	.196	.860	....	....	....
Aesculus pavia	.132	.232	.890	....	....	....
Cupuliferæ (Betuleæ):						
Alnus glutinosa	.088	.047	.930	− .012	− .019	− .199
Amygdaleæ:						
Amygdalus communis	.099	.093	.768	− .017	− .010	− .068
Amygdalus persica	.101	.071	.684	− .017	− .009	− .051
Aristolochiaceæ:						
Aristolochia sipho	.125	.243	....	− .035	− .053	....
Berberidaceæ:						
Berberis vulgaris	.092	.188	.748	− .026	− .036	− .182
Cupuliferæ (Betulaceæ):						
Betula alba	.112	.116	.743	− .034	− .050	− .010
Betula alnus	.121	.048	.875	....	....	....
Bignoniaceæ:						
Bignonia catalpa	.185	.472	.889	− .059	− .092	....
Euphorbiaceæ:						
Buxus sempervirens	.079	.087	.695	+ .071	− .013	....
Papilionaceæ:						
Caragana arborescens	.084	.168	.649	+ .016	− .050	− .201
Cupuliferæ:						
Carpinus betulus	.110	.120	....	− .020	− .035	....
Leguminosæ (Papilionaceæ):						
Cercis siliquastrum	.149	.192	.836	− .009	− .030	− .026
Colutea arborescens	.105	.270	.762	− .045	− .065	− .267
Tiliaceæ:						
Corchorus japonicus	.061	.125	....	+ .029	− .045	....
Cornaceæ:						
Cornus alba	.086	.211	.518	− .016	− .032	− .058
Cornus mascula	.119	.045	.691	− .015	− .010	− .077
Cornus sanguinea	.092	.251	.738	− .012	− .042	− .125
Cupuliferæ:						
Corylus avellana	.095	.021	.710	− .028	− .006	− .105
Pomaceæ:						
Cotoneaster vulgaris	.078	.192	.586	− .038	− .083	− .231
Rosaceæ:						
Cratægus coccinea	.110	.225	.831	....	....	....
Cratægus oxyacantha	.091	.210	.739	− .026	− .066	− .149
Leguminosæ:						
Cytisus laburnum	.117	.192	.705	− .027	− .050	− .151

Tabular summary of Linsser's results—Continued.

Orders, suborders, and species.	Physiological constants for zone A.			Departures of physiological constants for zone B from those of zone A.		
	Leafing.	Blooming.	Ripening.	Leafing.	Blooming.	Ripening.
Thymelæaceæ (Daphnoidæ):						
Daphne laureola	0.090	0.040	0.375	....	+0.080	....
Daphne mezereum	.061	.039	.433	+0.009	−.026	−0.163
Celastraceæ:						
Euonymus europæus	.110	.228	.852	−.036	−.078	−.232
Euonymus latifolius	.106	.192	.767	−.006	−.029	−.147
Euonymus verrucosus	.094	.253	.775	−.034	−.105	....
Cupuliferæ:						
Fagus castanea	.148	.352	.804	−.038	....	....
Fagus sylvatica	.152	.183	.737	−.050	−.053	−.217
Oleaceæ:						
Fraxinus excelsior	.161	.136	.845	−.049	−.050	−.365
Fraxinus ornus	.156	.184	.806	−.066	−.050	....
Leguminosæ (Papilionaceæ):						
Gleditschia triacanthos	.176	.310	....	−.036	−.094	....
Araliaceæ:						
Hedera helix	.120	.779	....	−.020	−.097	....
Elæagnaceæ:						
Hippophæ rhamnoides	.116	.133	.630	−.053	−.003	....
Ilicineæ (Aquifoliaceæ):						
Ilex aquifolium	.095	.231	....	+.055	−.111	....
Juglandaceæ:						
Juglans nigra	.202	.227	.798	−.102	−.077	....
Juglans regia	.161	.196	.794	−.059	−.060	−.046
Oleaceæ:						
Ligustrum vulgare	.082	.323	.841	−.017	−.055	−.121
Magnoliaceæ:						
Liriodendron tulipifera	.142	.343	.810	−.052	....	....
Caprifoliaceæ:						
Lonicera caprifolium	.050	.259	.670	−.030	−.060	....
Lonicera periclymenum	.049	.286	.663	−.009	−.033	−.133
Lonicera symphorycarpos	.072	.265	.766	....	....	....
Lonicera tatarica	.048	.177	.587	−.008	−.040	−.227
Lonicera xylosteum	.065	.190	.624	−.018	−.054	−.254
Pomaceæ:						
Mespilus germanica	.130	.246	.921	−.070	−.068	−.121
Magnoliaceæ:						
Magnolia yulan	.137	.108	.880	−.037	−.008	....
Urticaceæ:						
Morus alba	.166	.249	....	−.057	−.088	....
Morus nigra	.169	.267	.566	−.059	−.027	−.158
Saxifragaceæ:						
Philadelphus coronarius	.062	.265	.746	−.006	−.048	−.110
Philadelphus latifolius	.101	.316	.757	....	....	....
Coniferæ (Abietineæ):						
Pinus larix	.093	.098	....	−.019	−.028	....
Platanaceæ:						
Platanus occidentalis	.168	.276	.930	−.061	−.119	....

Tabular summary of Linsser's results—Continued.

Orders, suborders, and species.	Physiological constants for zone A.			Departures of physiological constants for zone B from those of zone A.		
	Leafing.	Blooming.	Ripening.	Leafing.	Blooming.	Ripening.
Salicaceæ:						
Populus alba	0.124	0.072	0.517	−0.030	−0.031	
Populus balsamifera	.108	.068	.300		+ .002	
Populus canescens		.074			− .026	
Populus fastigiata	.127	.080			− .050	
Populus nigra	.107	.093	.480	+ .010	− .024	−0.250
Populus tremula	.139	.050	.175	− .081	− .011	− .035
Amygdaleæ:						
Prunus armeniaca	.104	.066	.621	− .016	+ .002	− .199
Prunus avium	.090	.091	.421		+ .001	− .144
Prunus cerasus	.110	.123	.419	− .037	− .040	− .053
Prunus domestica	.107	.111	.659	− .013	− .009	− .095
Prunus padus	.091	.150	.545	− .036	− .042	− .185
Prunus spinosa	.093	.119		− .036	− .040	
Rutaceæ:						
Ptelea trifoliata	.156	.292		− .026	− .052	
Rosaceæ:						
Pyrus communis	.107	.123	.728	− .033	− .022	− .227
Pyrus cydonia	.103	.186	.827	+ .027	− .037	− .063
Pyrus japonica	.053	.074	.875			
Pyrus malus	.113	.160	.815	− .036	− .057	− .183
Pyrus spectabilis	.091	.152	.827		− .052	
Cupuliferæ:						
Quercus pedunculata	.150	.190	.849	− .050	− .055	− .111
Quercus robur	.130	.188		+ .010		
Quercus sessiliflora	.186	.225	.870	− .076	− .075	
Rhamnaceæ:						
Rhamnus cathartica	.114	.230	.800		− .098	
Rhamnus frangula	.128	.246	.777		− .069	− .367
Anacardiaceæ:						
Rhus cotinus	.176	.319	.560	− .093	− .136	− .146
Rhus typhina	.147	.416		− .037	− .110	
Saxifragaceæ:						
Ribes alpinum	.072	.111	.525		− .031	
Ribes grossularia	.051	.099	.454	− .030	− .033	− .073
Ribes nigrum	.069	.124	.438			
Ribes rubrum	.075	.112	.414	− .032	− .036	− .117
Leguminosæ:						
Robinia pseudo-acacia	.158	.269	.827	− .048	− .067	− .092
Robinia viscosa	.147	.288			− .048	
Rosaceæ:						
Rosa canina	.069	.297		+ .011	− .068	
Rosa centifolia	.111	.297	.794	− .044	− .050	− .054
Rosa gallica	.104	.315		− .074	− .101	
Rubus idæus	.082	.256	.460	− .035	− .072	− .085
Rubus odoratus	.126	.348	.480		− .042	
Salicaceæ:						
Salix alba	.122	.115	.294	− .062	− .067	
Salix capræa	.111	.057	.236	− .021	− .027	− .116
Salix fragilis	.097	.116	.340			

Tabular summary of Linsser's results—Continued.

Orders, suborders, and species.	Physiological constants for zone A.			Departures of physiological constants for zone B from those of zone A.		
	Leafing.	Blooming.	Ripening.	Leafing.	Blooming.	Ripening.
Caprifoliaceæ:						
Sambucus ebulus	0.105	0.361	0.750	....	+0.005	−0.150
Sambucus nigra	.067	.280	.674	−0.029	− .066	− .053
Sambucus racemosa	.069	.132	.526	− .039	− .018	− .173
Rosaceæ:						
Sorbus aucuparia (or Pyrus aucuparia)	.096	.202	.646	− .028	− .047	− .189
Spiræa bella	.094	.227	.790	....	....	....
Spiræa hypericifolia	.109	.199	.600	− .059	− .077	− .290
Spiræa lævigata	.050	.164	.680	....	....	....
Spiræa salicifolia	.077	.330	.820	....	− .156	....
Spiræa sorbifolia	.018	.381	.850	+ .052	− .156	− .270
Sapindaceæ:						
Staphylea pinnata	.094	.172	.713	+ .006	− .041	....
Staphylea trifoliata	.117	.180	.734	....	....	....
Saxifragaceæ:						
Syringa persica	.086	.183	.803	− .018	− .036	....
Syringa vulgaris	.078	.174	.740	− .005	− .049	− .025
Coniferæ:						
Taxus baccata	.127	.086	.748	+ .013	− .029	− .128
Tiliaceæ:						
Tilia europæa	.110	.385	....	....	....	....
Tilia grandifolia	.124	.366	.772	....	− .046	− .242
Tilia parvifolia	.136	.417	.806	− .032	− .087	− .108
Urticaceæ:						
Ulmus campestris	.127	.072	.244	− .043	− .028	− .067
Ulmus effusa	.113	.063	.286	− .003	− .015	− .096
Caprifoliaceæ (Loniceræ):						
Viburnum lantana	.091	.177	.706	− .051	− .057	− .152
Viburnum opulus	.100	.233	.780	− .027	− .075	− .258
Vitaceæ:						
Vitis vinifera	.164	.366	.821	− .051	− .076	− .108

In the original, from which the foregoing abstract is copied, Linsser gives the so-called probable error or the limit of uncertainty as deduced from the agreement among themselves of the numerous individual determinations of the physiological constants in zone A, whereas the mean values alone are given in our summary. It appears that the uncertainties are larger for the ripening phase than for the leafing and blooming phases, if we consider only their absolute values, but decidedly smaller if we consider their relative values. In general the uncertainty of the constant for leafing is about one-twentieth of its own value, the uncertainty of the constant for blooming is about one-fortieth of its own value, and the uncertainty of the constant for ripening is about one-fiftieth of its own value.

The values of the constants, as deduced from stations that lie in the dry zone B, vary much more than those in zone A; but this is a necessary consequence of the law of growth, since in such dry regions the quantity of heat required to produce a given phase ceases to be a simple constant and becomes a complex function of the available heat and moisture and depends upon the individual ratio f/w at each station. It will of course be noticed that, with few exceptions, the figures in the columns of departures are negative, thereby indicating that the quantities of heat actually utilized by plants in the dry localities in zone B are less than the quantities utilized by the same plant when it has an abundance of moisture in zone A. Most of the 17 positive figures among these departures relate to the period of leafing, and many of them are but little larger than the limit of uncertainty deduced by Linsser for the respective plants.

All of the plants investigated by Linsser belong, as is seen by the above list of names, to the exogens. They are also perennials, but his intention was to extend this investigation to the herbaceous annuals, and a large mass of work in this direction hàd been accomplished before his untimely death in 1871.

The conclusions drawn by Linsser from the data, as summarized in his published tables, may be presented as follows:

Although the general fact above mentioned, that plants growing in regions that have scant summer rains utilize less heat and less moisture to produce a given phase of development than similar plants having the same quantity of heat at their disposal with plenty of rain during the summer, might be considered as only a further consequence easily deduced from the principle that underlies the theory of Linsser's physiological constant, yet we may also consider the fact as one established empirically and seek for the most probable explanation. Any general relation between the vital phenomena of plants and their external influences can, according to the ideas established in Linsser's first memoir, be looked upon either as due to temporary influences or as a consequence of the habits of the plant. If we adopt the former view, then the cause of the accelerated development of plants in zone B will consist in the fact that from the beginning of vegetation onward one or more accelerating forces have come into play, the intensity and duration of whose action is greater for stations in zone B than in zone A. Such accelerating forces may consist in a greater quantity of heat or of sunshine or possibly other influences. But when we come to examine the temperature curves for stations in the two zones we see at once that heat alone can not be considered as the stimulating force. A similar comparison shows that rainfall during the growing season can not be the stimulus. Again, stations such as Parma and Pessan show that great differences in

sunshine alone fail to give a sufficient explanation. Finally, a natural and sufficient explanation is found in the study of the relation of the rainfall in summer to the given climatic conditions, as has already been done in the study of the heat; it is not the rainfall of the spring months that stimulates the plant, but it is the drought of the succeeding summer, or, as it were, the knowledge of that approaching drought which stimulates the plant to hasten and complete its development in the springtime or earliest summer. The plants of the north are accelerated because of the rapidly approaching autumn; the plants of the highlands because of the shortness of the approaching summer; the plants of the steppes and of regions with rainless summers hasten in order to have their work finished when the time arrives at which their activity should come to an end. The plants at localities in our zone B complete their labors in the springtime because of the drought of the coming summer; under almost the same external conditions the plants at Parma hasten their development while those at Venice live leisurely along; the plants at Vienna, Breslau, and Kief accelerate their growth, while the same plants at Heidelberg, Görlitz, and Orel live leisurely.

The problem, so often discussed, of the reforestation of the steppes is thus referred back to another more definite problem, viz., the acclimatization in the steppes of those plants whose normal cycle of vegetation in their native locality is such that when transplanted to the steppes these processes, especially the blossoming and leafing, can go on with sufficient rapidity to be completed before the beginning of the hot, dry summer. Quite similarly the problem of cultivation of fruit in those regions can be thus exactly defined. Thus Helmersen states that experiments with fruit trees brought from Hamburg to Orenburg entirely failed. But here we have to do with a double violation of the theory, since the plants brought from Hamburg came to a locality having a much smaller annual sum of heat and were not yet adjusted to the dryness of the Orenburg summers, wherefore they continued living at Orenburg according to the easy habit acquired at Hamburg. Linsser suggests that success would be much more likely if plants were taken to Orenburg from Bokhara or Khiva, where the extraordinary rapidity of development, on account of the great dryness of the summer following after a rainy spring is well known.

Further questions as to the temporary influence of rainfall during any part of a cycle of vegetation must be investigated by studying the life of plants at localities having very different climates.

After studies on the development of vegetation in various climates throughout the world, in all of which the rainy season is the blossom-

ing time, while the dry season is the ripening time, Linsser gives the following general conclusions:

There are two especial laws regulating the life of every individual plant, (1) the individual habit; and (2) the principle of economy. The application of these principles explains and gives us a better comprehension of the course of vegetation under the equator as well as near the pole.

The principal factors in the life of plants that we have thus far considered are heat and moisture. If the former is that whose periodicity gives warning of the necessity of economy, then the whole life of the plant is intimately dependent on the course of this heat, as in the extreme north and the greater part of the Temperate Zone where the moisture is otherwise sufficient. If it is the moisture that is subject to large periodical changes and the question of sufficiency of heat becomes unimportant because of its uninterrupted abundance, then the cycle of vegetable life depends upon the periodicity of this moisture, as in Madeira. If, finally, the variations of the climate are such that there is sometimes insufficient heat and moisture, then the necessity of economy in the use of both of these materials is enforced, and in the course of the year the plant seeks to develop as far as possible in accordance with both these necessities, as in the Steppes of southern Russia and near Bokhara and in isolated shady locations such as mountain sides.

The law of fractional parts of the total annual quantity of heat, as demonstrated in Linsser's first memoir, is therefore now seen to be only a special case, for northern and temperate latitudes, of the general proposition just enunciated. The former was the first approximation toward a rational theory of the periodical phenomena of vegetation, just as this more general proposition is the second approximation.

We have thus far studied principally the differences in the life of plants due to differences of climate in different localities. It still remained for Linsser to study the peculiarities of the same plants in different years in the same locality, to which end his manuscript material already offered a sufficient basis.

Of the questions proper to be considered in this second category, viz, the study of plant life as depending on temporary variations of local climates, Linsser enumerates the following as having already been taken up by him, viz: (1) The influence of cloudiness, insolation, and atmospheric pressure; (2) the especial influence of the various distributions of rain on the individual periods of vegetation; (3) the relation of the length of the day and the night, as also of light itself, on the plant; (4) the influence of the nonperiodic variations of temperature; (5) the influence of cold or warm winters on the subsequent summer's growth; (6) the investigation of the sums of tem-

perature for the same phases of plant life from year to year, and the reason of their variations. On this last point he concludes by stating that it is well known these sums do vary from year to year for each phenological epoch. For the present he states only that these temperature sums are not only apparently, but in reality, not constant, and from his preliminary work for this second series of studies the most important causes that determine the sum total had already become known to him. Without anticipating too much the course of further investigations, he states that studies already finished demonstrate that there should be differences annually in the temperature sums, as is evident from the following consideration: If seeds brought from Stuttgart to Christiania accelerate in successive generations in successive years because of the smaller sum total of heat in their new home, then exactly the same would occur if the plants remain in Stuttgart and we at that place offer them the sum total of heat peculiar to Christiania. That is to say, seeds that have ripened at any one place in colder years produce plants that develop more rapidly than do seeds from the same place but which were ripened in warmer years.

APPLICATION OF LINSSER'S RESULTS.

This application to each plant and each locality of the principle of economy which Linsser had established from the geographical distribution of plants offers to us by far the most important principle yet discovered and well established to guide us in the development of grains and plants appropriate to the vicissitudes of our climate. For instance, in general it is desirable to sow and plant so as to avoid the early autumn frosts and the late spring frosts—that is to say, to secure varieties of plants whose course of vegetation will be complete in the very short time that is free from danger of frost. Therefore, if we wish to develop plants that will ripen in the earliest summer, before the droughts destroy them, as in the region from Nebraska to Texas, then we have to remember that the seed perfected in Kansas in a dry year is already, by its own experiences, prepared to become the best seed for sowing in anticipation for the next dry year. The seeds raised in dry years should therefore always be preserved for sowing, as likely to be far more appropriate than any seed that may be brought from a distance, unless brought from a region where equally dry, short seasons prevail, as in southern Russia and Bokhara. The rule of sowing one year the seed raised the preceding year is, in general, not the best rule. By always utilizing as seed that which is raised in the driest years one may hope speedily to develop plants whose vegetating period will be so short that the crop will rarely be injured by the dry, hot winds of July. A similar rule holds good for any modification we desire to make in the seed. If we wish to

raise plants peculiarly fitted for wet climates or for cold climates, we begin with the seed that was ripened in wet or cold seasons.

I think that probably a further prosecution of Linsser's studies would have led to the conclusion that the influence of sunlight and diffuse sky light is the next important factor in vegetation, and that the quantity and quality of the seeds produced—that is to say, of the crop as distinguished from the mere epoch of ripening—depends upon the ratio of the nutrition carried up in the sap to the total intensity of sunshine. The grain harvests of the world may be divided into zones *a*, *b*, *c*, analogous to the phenological zones that Linsser has given, and in which the quantity of the harvests is large when the nutrition is sufficient to use up all the sunshine, but is small when either nutrition or sunshine is deficient. As the plant begins a new cycle so soon as the last is finished and usually is delayed by the speedy approach of winter cold or autumnal drought, therefore Linsser's laws would lead us to the conviction that by artificially regulating the temperature, moisture, sunshine, or artificial light, and the nutrition in the soil, we ought to be able to develop an ideal method of cultivation that should greatly increase the number of crops per year and the yield per acre, and especially so within small, limited areas that are protected by cover from injurious frosts.

The need of water for the varieties of plants and seeds usually cultivated has led to great engineering projects for irrigation, and the scarcity of natural rainfall has led to wholesale condemnation of many arid regions as being unfit for profitable agriculture, but the progress of knowledge now shows us that nature has a power at work gradually overcoming these disadvantages, and that man by taking advantage of her ways may profitably cultivate crops in extreme climates and soils, not so much by irrigation as by developing seeds and plants that suit the natural circumstances, just as our own ancestors developed our European grains from the grasses of Asia or our widespread maize from the weeds of Mexico. It is the duty of our agricultural experiment stations to lead the way in this evolution of new varieties quite as much as in the mere introduction or acclimatization and study of old varieties. Now that we have learned the secrets of Nature's method of evolution we must hasten to apply it to the needs of mankind.

DOVE.

In 1846 H. W. Dove wrote as follows:

In the tropical regions the mean temperature of any year differs but little from that of any other, but the quantity of rainfall differs largely. The result is that the yield of crops varies exceedingly, not only on lowlands that depend upon the periodical floods of the rivers, but also on the islands, where there are no large rivers. Therefore in these climates the agriculturist cares less about the temperature than about the rainfall.

In Europe, however, the connection between the temperature of the air and vegetation is so intimate that some investigators maintain that on the occurrence of a given temperature the plant enters at once upon a corresponding definite stage of development, while others maintain that in order to enter into this stage a definite sum total of heat must be received. Therefore the former determined the stages of development by the ordinates of the annual curve of temperature, while the latter determine them by the area of the space that is bounded by such ordinates. It is evident that if under a given latitude the temperature of the atmosphere is the principal factor, while under another latitude the moisture of the atmosphere is the principal factor, then neither of these should be entirely overlooked, but the part played by each must be examined. To this end the study of the geographical distribution of plants gives very little information. Again, the study of the influence of periodic variations of the atmosphere on plants is useless in the attempt to distinguish between the effects of temperature and moisture, because as a general rule the atmospheric conditions all attain their maxima and minima at about the same time. The study of the nonperiodic variations gives promise of greater success. But in studying the relation of temperature to vegetation the data given by thermometers hung in the shade, as to the temperature of the air, can have little to do with the life of the plant as compared with the temperature given by a thermometer exposed to the full sunshine by day and the radiation from the sky by night.

Dove then discusses the observations of maximum sunshine and minimum radiation thermometers made in the botanic garden at Chiswick, near London, from 1816 to 1840, and shows among other things that when the mean temperature of the air is low the freely exposed radiation thermometer is especially low, and when the average temperature is high the freely exposed solar thermometer is especially high. He then investigates the observations of earth temperature made by Quetelet, of Brussels, from 1834 to 1843, and shows that the upper layers of soil, whether dry or wet, have temperature variations parallel to those of the temperature of the air. He then studies the phenological observations of Eisenlohr at Carlsruhe from 1779 to 1830. These show that a plant enters into a definite stage of development when the air attains a definite degree of temperature rather than when the plant has received a definite sum total of heat, this conclusion being, of course, based upon the internal agreement of the computed figures for these fifty-one years of observations.

Analogous results were obtained by him by studying similar observations made in the State of New York and at Wurttemberg, Germany.

With regard to the influence of rainfall, Dove finds that it is not so plain as that of temperature, and that it is not so much the quantity of rainfall that is important as the frequency; too great fre-

quency is injurious, inasmuch as the cloudiness cuts off the influence of sunshine. The fact that years of low temperature are always years of poor crops is a fact that must be generally considered as a local phenomenon because of the simultaneous conpensation as to temperature that is continually going on in contiguous localities.

HOFFMAN.

Prof. Dr. H. Hoffmann published, first at Giessen and afterwards in the Memoirs of the Senckenberg Association at Frankfort (Vol. VIII, 1872), the details of a work which he began in Giessen in 1866 on the relation between the development of plants and the temperature recorded by a maximum thermometer in full sunshine. Some account of that work and its subsequent continuation at Giessen is given in successive papers published in the Journal of the Austrian Meteorological Association (Zeitschrift O. G. M.) during the years 1868 to 1891. The detailed references to these will be found in the list of papers appended to this present report. Hoffmann's first conclusion, as stated in 1868, was that he had found a precise, intelligible, and comparable expression for the quantity of heat that is needed for the attainment of any definite phase of vegetation. He would take the sum of the daily maxima of a thermometer fully exposed to the sunshine. His first work at Giessen was done with a naked glass bulb, self-registering, mercurial, maximum thermometer, graduated to Réaumur's scale, attached to a wooden frame and set out in full sunshine 4.5 French feet above the soil or green sod in an open portion of the botanic garden at Frankfort. The exposure was indeed not perfectly free, but was such that the sun shone upon the thermometer from sunrise to 2 p. m. in January and until 4.30 p. m. in June. Hoffmann's summations begin with midwinter, or January 1, and he gives the sums of the positive daily maxima (i. e., above 0° Réaum.) up to the dates of leafing and flowering for 10 plants.

Apparently preliminary values are given in the Journal of the Austrian Meteorological Society for 1868 and 1869, but final values in the memoir published at Frankfort, 1872.

In the Meteorologische Zeitschrift for 1875 Hoffmann says that after four years' work at Giessen (1866–1869) his thermometer was broken. A new one was constructed by Dr. J. Ziegler, of Frankfort, in accordance with their mutual understanding; this had a mercurial bulb, but was very many times larger than the former, and therefore very much more sluggish. Observations with such instruments, graduated to accord with the Réaumur scale, were begun in 1875 by Hoffmann at the botanic gardens at Giessen, and by Ziegler at the gardens at Frankfort. In order to compare these two series together and to unite them with the earlier Giessen series the ratios of the sums as given by the earlier and the later thermometers for the same

plant were taken, and it was found that the ratios are very nearly the same for all plants; therefore the ratio given by the best series, viz, for *Lonicera alpigena* was taken as a standard and applied to the series for the other plants, so as to reduce all observations with the later thermometers back to agreement with what would have been given by the first thermometer had it not been broken. The ratios of the sums observed at Giessen with the new thermometer as compared with the sums observed at Frankfort, also with a similar new thermometer, agreed closely for all the plants, and as the two new thermometers agree closely with each other when placed side by side, it was assumed that the ratios thus obtained represent the reduction from the climate of Frankfort to that of Giessen. Adopting the same standard plant and the ratio of its sums for any place to its sums at Giessen as the standard ratio, all the sums for plants at that place can be reduced to what would have been given by the same plants at Giessen and to what would have been given by the first Giessen thermometer. Although these reductions are very arbitrary, yet the agreement of the sums thus computed for Giessen with those actually observed was quite close. But, as we shall see, subsequent years of observations have shown that such agreements do not always recur.

In the Zeitschrift for 1881 Hoffmann shows that it is not the low temperatures but the subsequent too rapid thawing that injures most plants; thus the hill stations suffered less at the close of a period whose lowest temperature was —31° Réaum. than did the plants in the lowlands; the shady side of the tree suffered less than the sunny side. It is indifferent whether the sudden rise in temperature is caused by great solar rays or by a sudden warm wind; the sudden rise from —12° Réaum. to +13° Réaum. is as bad for plants as the sudden rise from —20° Réaum. to +5° Réaum.; the amount of injury is proportional to the extent and to the suddenness of the rise.

In the same volume of the Zeitschrift (p. 330) Hoffmann gives the results of observations at Giessen for 1880. He finds that the blossoming in springtime is so subject to disturbances by frost that the midsummer and autumnal phases of vegetation are more proper to show the accuracy of his methods. He finds that these later phases, as observed at Giessen (1866–1869), when reduced to the new standard thermometer at Giessen agree within 1 per cent with the actual observations of 1880 at that place. For plants that bloom in the spring he finds that if these are protected from injury by frost by placing them under glass covers there is then a better but still unsatisfactory agreement between the observations at Giessen and Frankfort. On computing the mean temperature of the air in the shade for the dates of blooming at Giessen he finds no apparent connection, so that from the date of blooming we can not infer the mean temperature of that day nor can we reason from the temperature to the date.

The sum total of daily maximum sun temperatures at Giessen is much more nearly constant.

In the Zeitschrift for 1882 Hoffmann gives the sums of the daily positive readings of his naked bright-bulb mercurial thermometer in the full sunshine; he also gives the sums of the temperature in the shade, and computes the average discrepancy or probable error of these numbers as deduced from their internal agreement year by year. He finds the probable uncertainty of the sums of maxima to be plus or minus 1 per cent and of the sums of shade temperatures to be plus or minus 10 per cent. These latter sums relate to low-lying stations, such as Vienna and Dorpat, and these discrepancies diminish very much when we consider high mountain stations, where the shade temperatures of course give much smaller sum totals. He recognizes that the advantage of using the shade temperatures lies in the greater comparability of the observations made at different stations and with different instruments, but that the sunshine method is also greatly improved if the thermometers are perfectly similar and properly compared together, as in the instruments made by Doctor Ziegler at Frankfort. (See the report of the Senckenburg Association, 1879–1880, p. 337.) Hoffman's observations with a variety of instruments convinced him that this difficulty as to instruments and exposures is not insurmountable. He collects comparative readings at several places and shows that the difference between the average temperatures in the sun and in the shade is larger at higher altitudes; thus at Giessen the average difference in summer at midday is 5° Réaum., and the whole range of the differences between sunshine and shade is from 3° to 15° Réaum. The corresponding average in the Hochgebirge, 7,000 feet, is never less than 8° Réaum. At the Bernina hospice, 8,113 feet, it is 25° Réaum. The average temperature of these mountain stations is 16.4° Réaum., corresponding to an elevation of about 6,000 feet. Similarly, J. D. Hooker observing a black-bulb thermometer in the sunshine in the Himalayas, found a difference of —15° Réaum. at 7,400 feet elevation, as contrasted with 4.4° at sea level. R. S. Ball, also using a black bulb, finds a difference of 18° or 20° Réaum. in the Hochgebirge and of only 3° at Chiswick.

These differences show the effect of the great dryness and mechanical purity of the air in the Hochgebirge. Hoffmann considers the smoke and clouds above us as affecting the difference between the sun and shade thermometers, but says nothing of the earth's surface which completes the "inclosure" of the thermometer.

The date from which Hoffmann begins his summation for Giessen is January 1; but as it would seem more proper to begin with some definite phase of vegetation, therefore he investigates the accuracy with which we can determine the initial phase and the effect of errors therein upon the ultimate sums. By painting the buds of certain

trees and examining them very frequently Hoffmann seeks to determine how accurately the date of the beginning of vegetation or the flow of sap can be determined by the swelling of the buds and the visible cracking of the delicate pencil lines of paint. He finds that the date can be determined to within one day when spring comes on rapidly, but within eight days when it comes very slowly. The corresponding uncertainty or variability of the sums of the maximum sunshine thermometer from the swelling of the buds up to the date of the first blossom, for instance, for *Castanea vulgaris*, is 4 per cent while the uncertainty of similar sums, counting from January 1, is only 1 per cent. These and similar data are only deducible from observations made upon the same tree or bush from year to year; the variations are materially increased when different plants in different localities are observed; moreover, they are based upon observations for only four years, which period is not long enough to give a reliable value of the relative uncertainties. As in previous cases in making up these abstracts, I give Hoffmann's actual figures in the following summary, which I have compiled by collating the few observations published by him in the Zeitschrift during the years 1870–1890. I have selected only the few plants for which he has published the sums for several years or for two localities, so that comparisons may be made and a judgment arrived at as to the propriety of his method. It will be observed that Hoffmann has, when possible, observed the same tree or bush from year to year, so that the problem of the influence of heat is much more definite than when different plants or a general mass of plants is observed; but, on the other hand, single plants are more liable to irregularities produced by special disturbances which would exert no appreciable influence on the average of a large number of similar plants.

Temperature sums at Giessen (Hoffmann's method) from the first swelling of the buds to the first blossom.

[Z. O. G. M., Vol. XVII, 1882, p. 127. All in Réaumur degrees.]

Plant.	1866.	1867.	1868.	1869.
Castanea vulgaris	2,044	2,142	2,085	2,317
Catalpa syringafolia	....	2,149	1,964	2,547
Lonicera alpigena:				
First specimen	....	891	1,058	1,014
Second specimen	....	919	1,058	1,032
Persica vulgaris:				
First specimen	659	678	774	788
Second specimen	893	670	984	....
Syringa vulgaris:				
First specimen	1,388	....	1,315	1,248
Second specimen	1,299	....	1,181	1,166
Vitis vinifera:				
First specimen	....	....	1,040	1,531
Second specimen	....	....	856	1,222

Temperature sums from January 1 to the date of first blossom (by Hoffmann's method) at Giessen and at Frankfort.

[Z. O. G. M., Vol. X, 1875, p. 251, and Vol. XVI, p. 331. All in Réaumur degrees.]

Plant.	Giessen.				Frankfort, 1875, thermometer B_2.
	1866–1869, thermometer A.	1875, thermometer B.	1880.		
			Thermometer B_1.	Thermometer B_2.	
Lonicera alpigena	1,167	916			
Sambucus nigra	1,678	1,315			
Berberis vulgaris	1,377	1,091			1,110
Prunus avium	1,077	820			800
Syringa vulgaris	1,393	1,091			
Aesculus hippocastanum	1,317	1,069			1,065
Vitis vinifera	2,600	1,995	2,697	2,603	
Prunus spinosa		819			822

Temperature sums (by Hoffmann's method) at Giessen from January 1 to first blossom, for plants that blossom in midsummer and autumn.

[Z. O. G. M., Vol. XVI, p. 331, and Vol. XVII, p. 130; M. Z., Vol. I, p. 407, and Vol. III, p. 546.]

Plant (always same stock).	Thermometer A, 1866–1869.	Thermometer B_1.		Thermometer B_2.						
		1880.	1881.	1880.	1881.	1882.	1883.	1884.	1885.	1886.
Aesculus macrostachya	3,353	3,504	3,479	3,191	3,254	3,929	3,846	3,639	3,546	3,556
Aster amellus	3,930	4,091	4,003	3,753	3,768	4,522	4,569	4,363		
Lilium candidum	2,710	2,872	2,855	2,603	2,639	3,112	3,228	3,010		
Linosyris vulgaris	4,033	4,091	4,260	3,753	4,040	4,555	4,670	4,502		
Plumbago europaea	5,318	5,495	5,261	5,054	5,017				5,386	5,494
Pulicaria dysenterica	3,381	3,618	3,263	3,753	3,045					

The contrast between the ordinary spring of 1881 and the very early spring of 1882 with its preceding warm winter, affords a test of the question as to how much the thermal constant is liable to change with the variations in the seasons. Hoffmann finds that although the first blossoms in the spring of 1882 occurred fifteen days earlier than usual, yet the sums of the maximum temperatures since January 1 were not much changed. The figures as given by him (Z. O. G. M., Vol. XVII, p. 460) are reproduced as follows:

Plant.	Thermal sums.		Date of blossoming.	
	1881.	1882.	1881.	1882.
Carpinus betulus	1,159.7	1,134.6	Apr. 19	Apr. 2
Larix europaea	789.9	759.9	Mar. 30	Mar. 15
Lonicera alpigena	1,471.7	1,490.4	May 6	Apr. 19
Prunus spinosa	1,159.7	1,091.6	Apr. 19	Mar. 31
Ribes grossularia	1,086.5	1,091.6	Apr. 16	Mar. 31
Crataegus oxyacantha	1,681.6	1,732.5	May 15	Apr. 30
Sarothamnus vulgaris	1,790.8	1,751.9	May 20	May 1
Berberis vulgaris	1,681.6	1,751.9	May 15	May 1

Many of the plants observed by Hoffmann show such discordant sums from year to year as to prove that his method has no meaning for them, but for others the agreement is such that he recommends them to be observed in connection with the observations of the sunshine thermometer, as follows:

For the following plants observe the temperature sums from the first swelling of the buds to the first flower blossom: *Castanea vesca*, *Bupleurum falcatum*, *Corydalis fabacea*, *Dianthus carthusianorum*, *Lonicera alpigena*, *Salix daphanoides*, *Syringa vulgaris*, *Amygdalus nana*, *Alnus incana*, *Alnus viridis*, *Atropa belladonna*, *Betula alba*, *Crataegus oxyacantha*, *Larix europaea* (up to the date when the pollen first falls from the anthers), *Ligustrum vulgare*, *Lonicera tatarica*, *Prenanthes purpurea*, *Prunus padus*, *Prunus spinosa*, *Rhamnus frangula*, *Ribes aureum*, *Rosa arvensis*, *Rosa alpina*, *Salix caprea*, male (for the catkin, or the flowers of the willow, the beginning of pollination, as ascertained by a light stroke on the flower, is to be considered as the date of the first blossom).

Hoffmann also applies his summation of sunshine maxima temperatures to the interval from January 1 to the ripening of the fruits and shows an excellent agreement between the numbers for 1880 and those for 1881 at Giessen.

In the Zeitschrift for 1884 Hoffmann gives his results for 1882, 1883, and 1884 as collected in the preceding table and says that the vexed question of the thermal constant for vegetation is still far from being settled; either temperature and vegetation are independent of each other, which no one can easily believe, or they stand to each other in a relation for which the correct expression is still unknown. Pfeffer in his Pflanzen Physiologie (Vol. II, p. 114) has stated that the approximate uniformity of the sums of temperature, from year to year, can only mean that, in general, for each year the heat received from the sun amounts to about the same sum total for the same date annually; but this is not in strict accordance with facts, for if it were true a small change in the date should make a small change in the sums, which is not always the case. Thus, if for *Linosyris vulgaris* the dates of blossoming are August 15, 18, or 20, the sums from January 1 for different years will be as follows:

Year.	Aug. 15.	Aug. 18.	Aug. 20.
1882	4,555	4,637	4,698
1883	4,597	4,670	4,728
1884	4,363	4,452	4,500

From these figures we see that the sums vary from year to year quite independently of the change of date.

The thermometer B_1, similar to B_2, having been sent to Upsala for observations at that place, it gave from January 1 to the first blossom

sums that agree so well with those found at Giessen that Hoffmann thinks no better can be expected.

In the Zeitschrift for 1885 Hoffmann continues to give the comparative observations at Giessen and Upsala, and remarks that the question is not as to whether his method is correct and the others are wrong, but as to which of all methods is even a little better than the others. Of these others only one can, he thinks, be compared with his own, viz, that of Karl Fritsch, who takes the sum of all positive mean daily shade temperatures. Hoffmann applies Fritsch's method to the observations at Giessen and Upsala and finds the argument not in its favor. He also tries another form of thermometer, viz, the so-called black bulb in vacuo, but finds it too sensitive, which he thinks is because its bulb is too small.

In the Zeitschrift for 1886 (p. 546) Hoffmann gives a summary of observations at Giessen and Upsala during 1886. In general the sums are smaller at Upsala and so also for high Alpine stations. He is thus led to the laws established by Karl Linsser, as published in St. Petersburg in 1867 and 1869, which laws he expresses as follows: "Every wild plant has in the course of time so adapted itself to the surrounding local climate that it utilizes this climate to the best advantage. For any given phase of vegetation it uses a certain proportional part of the available annual sum total of heat. Thus, if the annual sum at Venice is 4,000 and if the corresponding sum at St. Petersburg is 2,000 and if the plant utilizes one-fourth in order to bring it to the flowering stage, then it will require 1,000 at Venice and 500 at St. Petersburg." From Linsser's law he concludes; (1) plants that have been raised in the north and are transplanted to the south reach their phenological epochs earlier than plants already living there, while southerly plants carried to the north are retarded as compared with those already acclimatized; (2) plants raised on colder highlands when transplanted to the warmer lowlands have their epochs accelerated as compared with those already domesticated; plants raised in the lowlands and transplanted to the colder highlands develop more slowly than the acclimatized plants.

In the Zeitschrift for 1886 (p. 113) Hoffmann determines the relative retardation of vegetation as determined by the dates of the first blossom of several plants at different altitudes. The result is for the *Pyrus communis* (pear tree) and allied varieties a retardation of 3.7 days per 100 meters, and corresponding to this a retardation of 2.8 days per 1° of latitude. The analogous data for *Pyrus malus* (apples) are 2 days per 100 meters and 4.4 days per 1° of latitude. Charts are given showing by means of isophenological lines the gradual progress northward of the development of vegetation as spring advances.

In Petermann's Geog. Mitth. for 1881 Hoffmann gives a general phenological chart for central Europe showing the acceleration or retardation of the phases of vegetation with respect to Giessen.

In the Zeitschrift, 1882, Vol. XVII, page 457, Hoffmann gives the results of his study of observations collected by Karl Fritsch, showing the dates of blossoming and ripening of fruits in Europe, as reduced to the latitude and altitude of Giessen; and, second, the thermal constant by Hoffmann's method from observations at Giessen for the years 1881 and 1882, as collated in the preceding table. He also shows that the advance of vegetation in the early and very warm spring of 1882 did not materially diminish the sums total of maximum temperatures, the figures for which I have reproduced in the preceding table (p. 240).

MARIÉ-DAVY.

The extensive researches conducted at the observatory of Montsouris (Paris) are scattered through many annual volumes, from which I have culled sufficient to show the views held by Marié-Davy and his coworkers, who distinguish very clearly between thermometry and actinometry, and attempt to determine separately the constant amounts of air temperature and of sunshine which constitute the total molecular energy needed to develop the plant.

In his Annuaire for 1877 Marié-Davy quotes from Tisserand (1875) and Schuebeler (1862) the results of a series of observations on the culture of grain in Europe. Special praise is given to the records from Norway and to the high state of education among the Norwegian farmers. The durations of the periods from sowing to ripening are as follows:

Locality.	Latitude.	Mean annual temperature.	Sowing to ripening.		
			Spring wheat.	Spring rye.	Four-row barley.
	° N.	*° C.*	*Days.*	*Days.*	*Days.*
Halsno	59.47	6.3	133	139	117
Bodo	67.17	3.6	121	118	102
Strand	68.46	2.9	115	116	98
Skibotten	69.28	2.3	114	113	93
Algiers	36.45		142		
Paris (Fouilleuse)	48.50		139		

For other plants—oats, peas, beans, vetches, etc.—the duration of the vegetating period diminishes in a similar manner as the latitude increases or as the temperature diminishes; therefore we can not assume at once that warmth hastens the ripening, for in this case cold appears to hasten it. I say "appears," because with the cold comes in another influence, viz, the amount of sunshine. Thus as we go

northward we have a greater amount of possible sunshine during the growing period, although the actual sunshine is very materially diminished by the quantity of cloud and fog. Tisserand calls attention to the maximum possible duration of sunshine as given in the following table for the season of spring wheat from sowing to ripening:

Latitude north.		Maximum sunshine duration.	Corresponding locality.
°	'	*Hours.*	
48	30	1,996	Alsace.
59	0	1,795	Christiania.
59	30	2,187	Halsno.
67	0	2,376	Bodo.
68	00	2,472	Strand.
69	30	2,486	Skibotten.

These numbers of possible hours of sunshine should be diminished to actual hours of sunshine on account of cloudiness. Moreover, actual actinometric observations would have shown that owing to the atmospheric absorption the efficiency of the sunshine is less at low altitudes and, therefore, at high latitudes. But in the absence of fundumental climatic data Tisserand is probably correct in concluding that the temperature of the air has apparently little to do, in and of itself, with the duration of the time from sowing to ripening, but that this depends principally on the sunshine, so that at northern latitudes the wheat ripens best in localities that have the least cloudiness or the sunniest exposure. On the other hand, the temperature of the air does appear to materially affect the chemical constitution of the grain, since the northern crops are richer in hydrocarbons, and the proportion and quality of the starchy principle increases and the nitrogenous compounds diminish as the locality approaches the equator.

The acclimatization of plants is accompanied by notable changes in their nature; frequently the leaves increase in size relatively to the rest of the plant, and their colors are more pronounced, as if the plant sought to supplement the low temperature by a more complete absorption of the solar rays. A similar change as to the leaves and colors takes place in the flora of high mountains as compared with that of the plains below. The aromatic principles of plants are also developed in a remarkable manner in high latitudes. Thus the beans have a more decided flavor in Norway in proportion as we go northward, and at Alten (lat. 70° N.) the most aromatic cumin (*Cuminum cyminum*) of all Europe is cultivated.

The incident sunshine seems to be the productive climatic element in effecting the growth of plants; it furnishes the total vis viva, or

the mechanical or molecular energy, that is at the disposition of the plant, but it is also the last consideration to be studied and understood.

The temperature is the next important climatic element and that which has been most studied; the heat involved in temperature is the mechanical, molecular energy that is utilized by the vital powers of the plant.[a] Each plant utilizes a fraction of the molecular energy that is at its disposition, according as its sunshine, temperature, and sap are favorable to the formation of the chemical substances that it can elaborate within its cells. The remaining elements important to the production of crops are:

(*a*) The water that enters the root, which may be natural rain or artificial irrigation.

(*b*) The chemicals dissolved in the water.

(*c*) The soil that furnishes these chemicals.

(*d*) The atmosphere that furnishes nitrogen, oxygen, and carbonic-acid gas.

(*e*) The evaporation of moisture from the plant and soil, mostly through the influence of the wind and heat.

Of these, only the rain water, the gases in the atmosphere, and the evaporation are, properly speaking, meteorological or climatic elements not under the control of man; whereas the irrigation of the soil and its chemical constitutents are largely under his control.

The quantity of water actually consumed by the plant or evaporated from its leaves and that which is daily evaporated from the soil or which drains away to other localities, and thus becomes useless to the plant, have been the subject of many experiments, some of whose results may be summarized as follows:

Thus, for example, Lawes and Gilbert, at Rothamsted, England, from experiments in vases entirely under their control, derived the following numbers, showing the weight of water evaporated relative to the weight of grain produced per unit area of ground:

Manure.	Weight of grain.	Weight of evaporated water.	Ratio.
	Grams.	*Grams.*	
None	9.6	7,353	766
Mineral fertilizers	7.2	6,438	882
Mineral and ammoniacal fertilizers	4.2	3,627	864

In these experiments, therefore, the ground during the wheat season consumed water equivalent to a rainfall of from 184 to 212 millimeters in order to produce a harvest of 30 hectoliters, or 80 kilograms in weight per hectare.

[a] Is it not in fact *the* vital power of the plant?—C. A.

Thus, again, Risler, at Calèves, in France, measured the harvest and the rainfall in an open field, having an impermeable subsoil. He measured the quantity of rainfall and the outflow through the drains, and allowed for the moisture in the soil at the beginning and end of his experiments. The result attained was that a field of winter wheat consumed 256 millimeters in depth of water from April to July. He does not give the quantity of grain that was harvested.

Marié-Davy, at Montsouris, cultivated winter wheat in twelve samples of earth of very different qualities, in 1874. The soil was enriched with compost, with results as in the first part of the following table.

In 1875 the soil was enriched with Joulie's complete fertilizer for cereals at the rate of 1,000 kilograms per hectare, with results as in the second part of the table.

Evaporation and crops at Montsouris.

Sample No.—	Experiment of 1874.			Experiment of 1875.		
	Evaporation.	Crop.	Ratio.	Evaporation.	Crop.	Ratio.
	Kilos.	*Grams.*		*Kilos.*	*Grams.*	
1	380	394	964	362	394	919
2	360	187	1,924	356	372	957
3	348	300	1,160	345	474	728
4	347	380	913	364	479	760
5	340	303	1,122	356	425	837
6	365	256	1,426	363	262	1,386
7	344	328	1,049	366	435	841
8	329	324	1,015	344	424	811
9	339	312	1,086	346	387	894
10	359	308	1,165	366	379	965
11	346	313	1,105	346	469	738
12	372	236	1,576	363	379	958
Average	352	303	1,140	356	407	877

We remark that in these two years the quantity of water evaporated has remained the same, but the harvest changed notably, being in both cases much superior to those of Rothamsted and Calèves. A box of earth, similar to those containing the wheat, lost by evaporation from January 26 to June 9, 1875, 114 millimeters, while a box planted with wheat lost 356 millimeters, and the Piche evaporimeter lost 302 millimeters. Similarly, in 1876, from the 22d of February to the 5th of July, the soil covered with winter wheat lost 426 millimeters, but the naked soil 163 millimeters and the Piche 465 millimeters. However, in this connection it must be noted that while the boxes containing naked soil received only the natural rainfall, those containing the growing plants received weekly the water that they

had lost by evaporation the preceding week. These latter, therefore, show us the maximum effect that water can have on vegetation in the climate of Paris. The proportion of water that is consumed is exaggerated, but the crop increases at the same time, but less rapidly than the consumption of water. We may, therefore, say that to a certain extent, water can with the aid of the sunshine supplement the fertilizers, although we can not say that a deficiency of fertilizer is a good thing.

In general, all the observations recorded in France, Switzerland, and England show that the total annual evaporation from cultivated soils is 70 to 80 per cent of the total annual rainfall. A large part of the rain falls in the autumn and winter when vegetation has ceased. The rains of these seasons partly filter into the earth and feed the subterranean springs, but they must first return to the soil its own water supply. Now the more the soil is impoverished by cutting the crops the more it will take up of the autumn rains and the less will be received by the subterranean water beds. It is then easy to understand that in cultivated lands the mean flow in the water courses diminishes in proportion to the progress of the cultivation. It seems certain that in France, and especially in the central portions, the grains do not find in the soil all the water that they could profitably use to the advantage of the crop and that irrigation would be advantageous in these and many other crops wherever there is a good soil and an abundance of sunshine.

Notwithstanding this necessity for water, the rainy years are frequently bad for cereals. Rainy summers are deficient in light and dry summers have too much. It is the relative distribution of heat, sunshine, and moisture from day to day throughout the whole season that is important.

From a meteorological point of view we should say that from the sowing to the formation of the embryo grain sunlight is indispensable, but from the formation to the maturity it is far less important.

In his Annuaire for 1878 (p. 468) Marié-Davy gives a summary of the meteorological data, month by month, for several years, as a sample of what may be done by way of explaining the general relations between meteorology, as hitherto pursued, and the crops of the agriculturist. He says:

Meteorology, as seen from the agricultural point of view, has for its ultimate object to enable the farmer to anticipate the future of his current crop. This explains why we think it necessary to study the influence that each of the meteorological elements has on the progress of the development of the plants in the successive phases

of their growth. The tables of statistics of the climate and the crops, or the corresponding graphic diagrams, allow us to take exact account of the features of the past years and to approximately compare these characteristics with the agricultural features of the current year. Let us compare among themselves the five crops for the years from 1873 to 1877. Of these five years, 1873 gave a poor crop. On the contrary, 1874 gave a very good crop, both as to quantity and quality. The crop of 1875 attained an average as to quantity, but the quality of the grain was below the average. Notwithstanding the great irregularities of 1876 it gave us a good average as to quantity and excellent grain as to quality. In 1877, notwithstanding a great development of straw or stalks, the crop of grain was below the average as to quantity and quality; therefore, as regards their crops of grain, these years can be classed in the following decreasing order: 1874, 1876, 1875, 1877, 1873.

We will compare these harvests with the following meteorological tables for these years, as based on observations at Montsouris:

MONTHLY RAINFALL.

Month.	1872–73.	1873–74.	1874–75.	1875–76.	1876–77.
	mm.	*mm.*	*mm.*	*mm.*	*mm.*
October	66.9	65.2	51.0	76.9	29.2
November	128.1	36.5	44.2	75.4	51.0
December	84.6	6.0	81.8	22.4	34.8
January	37.3	23.1	63.2	9.1	42.2
February	59.1	17.5	10.9	57.8	42.9
March	40.4	11.4	8.6	62.7	70.5
April	44.5	16.1	10.1	24.3	55.9
May	45.2	36.6	24.6	14.3	69.5
June	137.9	47.8	82.0	70.6	66.7
July	38.8	54.5	82.1	24.6	57.7
August	42.7	23.1	73.7	72.3	36.7
September	53.6	65.1	32.8	65.3	50.1

MONTHLY EVAPORATIONS, AS MEASURED BY THE PICHE EVAPORIMETER.

	mm.	*mm.*	*mm.*	*mm.*	*mm.*
October	58.2	52.1	47.1	26.8	39.3
November	55.4	52.9	34.1	40.8	33.1
December	48.3	22.4	32.0	11.3	58.9
January	....	36.8	34.0	8.0	53.3
February	....	50.5	25.0	31.5	40.5
March	85.5	80.6	84.3	63.3	46.5
April	110.5	99.0	135.0	107.2	90.5
May	121.7	110.0	115.0	147.5	90.8
June	97.4	142.8	92.3	115.8	120.7
July	121.7	149.8	81.5	144.2	99.2
August	129.7	130.6	84.7	123.7	93.8
September	72.4	78.3	65.6	44.2	63.0

DEGREES OF HEAT OR MONTHLY SUMS OF THE MEAN DAILY TEMPERATURES.

Month.	1872-73.	1873-74.	1874-75.	1875-76.	1876-77.
	°C.	°C.	°C.	°C.	°C.
October	326	350	360	291	406
November	258	216	180	186	213
December	202	99	22	71	220
January	152	146	167	3	198
February	62	120	48	122	196
March	254	223	174	205	183
April	267	312	312	301	303
May	375	366	487	355	357
June	510	528	528	500	594
July	628	667	552	634	570
August	601	561	608	606	583
September	435	507	534	453	390

DEGREES OF LIGHT OR MONTHLY SUMS OF THE MEAN DAILY ACTINOMETRIC DEGREES.

	°*Actin.*	°*Actin.*	°*Actin.*	°*Actin.*	°*Actin.*
October	552	598	738	604	583
November	276	403	414	372	195
December	332	282	285	267	233
January	440	397	363	406	363
February	353	490	426	453	353
March	791	871	766	800	763
April	909	1,152	1,248	1,191	1,050
May	1,401	1,442	1,453	1,432	1,134
June	1,398	1,566	1,359	1,458	1,622
July	1,702	1,590	1,428	1,569	1,439
August	1,376	1,311	1,172	1,243	1,254
September	930	945	1,041	900	898

Our summaries are divided into three periods. The first, October to February, corresponds to the sowing and the winter season; the second, March to July, corresponds to the vegetation of the cereals; the third, May to September, corresponds to vegetation of the vine. In these summaries the years are rearranged in the order of the decreasing value of the grain harvest.

Summary from October to February.

	1873-74.	1875-76.	1874-75.	1876-77.	1872-73.
Rainfall	148	242	251	200	376
Evaporation	215	118	172	225	....
Degrees of heat	931	673	777	1,233	1,000
Degrees of light	2,187	2,102	2,226	1,727	1,953

In the first period, or the winter, the climatological facts have very little apparent bearing on the crops. The sowing period may have been more or less difficult, but very pronounced anomalies in the climate must occur in order to compromise the harvest in an irremediable manner. The year 1872–73 is the only one that presents a fact of

this latter kind. The excessive rains of autumn drowned the wheat and produced disastrous inundations. Up to that time we perceived the influence of the light, which strengthens the young shoots and gives them a real progress, but which may be promptly effaced by the subsequent bad weather.

Summary from March to July.

	1873-74.	1875-76.	1874-75.	1876-77.	1872-73.
Rainfall	166	197	207	320	307
Evaporation	582	558	508	448	537
Degrees of heat	2,096	1,995	2,053	2,007	2,029
Degrees of light	6,621	6,450	6,249	6,008	6,201

In the second period the light is the element which appears to be of the least importance. Its variations do not correspond to the value of harvest attributed to each year. It is not the same with the rainfall, which increases regularly in proportion as the harvest becomes less favorable. The two last years, 1877 and 1873, differ little from each other in general characteristics.

Experience shows that we may water grain planted in pots or in free earth every day and only increase the quantity and quality of their product instead of diminishing them. It is not, therefore, that rain water in itself is injurious—far from it; but rainfall brings with it cloudy weather, which diminishes the light. We see in fact that the sum of the actinometric degrees decreases regularly in proportion to the increase in the value of the crop year, except in the case of the last year, 1873, which only descended to this rank in consequence of the meteorological accidents of the autumn. In reality 1873 would have been a more favorable year for the crops than 1877 if the autumn had not been so exceptionally unfavorable. The crop of 1877 only recovered its value, because of the abundance of the wheat stalks. Thus we see that it is in vain that the season be favorable as regards weather if the heads of the grain are scarce.

Résumés from May to September.

	1873-74.	1875-76.	1874-75.	1876-77.	1872-73.
Rainfall	227	247	295	281	318
Evaporation	612	575	439	468	543
Degrees of heat	2,629	2,548	2,709	2,494	2,544
Degrees of light	6,854	6,602	6,448	6,347	6,807

This third period relates to the wine crop. During this period, as in the others, heat seems to play only a very secondary part for the same country. There would not be the same difference in the nature of the product from one country to another. On the contrary, the quantity of light decreases regularly from the first or best crop to the year before the last or poorest crop. The last year, on the other hand, which was so bad at the beginning, recovered in a most extraordinary manner at the end, and as regards the quality of the

wine this year should have had a great similarity with 1874. Nevertheless, the wine of 1873 was not of very good quality, which can perhaps be attributed to a too prolonged growth of the vine stems, caused by the humidity of the soil. If in general a good wheat year corresponds with a good wine year this rule is far from invariable. In regard to quality the vintage depends but too often on the late spring frosts.

The extremely important part played by light in agriculture makes us regret that the actinometer should still be so little known. It perfectly replaces the thermometer for agricultural purposes, but the thermometer can not take its place.

In his Annuaire for 1882 Marié-Davy gives the following study of the development of cereals, wine, and other crops:

Cereals.—The cereals offer a great number of varieties, and this number increases annually, but often the differences that we see between them are due to certain influences of the soil and climate which disappear by change of locality. However, there are some varieties whose qualities have been fixed by long-continued cultivation in the ordinary way or by long-continued selection, and which present decided advantages for the specific climates.

The varieties brought from the south are more sensitive to cold than those from the north, and can not be propagated without special precautions in higher latitudes or at greater altitudes than belong to the localities where these varieties were gradually developed. The varieties brought from the north are generally more precocious and suffer more from dryness. The expressions "early" or "late" have reference to their behavior in the new locality. The grain brought from the south comes to maturity at a later date than that raised in the north.

Influence of heat and light on development of wheat.—We shall divide the development of wheat into four phases, whose dividing epochs are the processes of (1) sowing and germination, (2) heading out, (3) flowering, and (4) ripening. According to Gasparin the germination of wheat begins when together with the necessary moisture it also enjoys a temperature in excess of 5° C., and it sprouts when it has received a sum total of effective mean daily temperatures (above 5° C.) equal to 84° C. Its sprouts shoot above the soil a few days later. Some wheat sown by Marié-Davy April 23, 1880, was up on the 4th of May, the sum of the mean temperatures being 96°, so that the germinating sprout had taken about two days to grow from the seed to the surface. In the following table columns 2, 3, 4, and 5 show the duration in days of the period required for the germination of wheat supposed to be sown at Montsouris in the different years on four different dates—*a*, *b*, *c*, *d*—as stated at the heads of the columns. These durations are calculated to the nearest whole days, on the

assumption that the sum of the mean daily temperatures in the shade must be 84° C.

[Date of sowing: *a*, October 1; *b*, October 15; c, November 1; *d*, November 15. Average date of germination: *a*, October 7; *b*, October 22; *c*, November 14; *d*, December 18. Average date of heading: *a*, February 8; *b*, March 4; *c*, March 3; *d*, February 26.]

Year.	Duration of germinating stage.				Duration of heading stage.			
	a.	*b.*	*c.*	*d.*	*a.*	*b.*	*c.*	*d.*
	Days.	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*
1873	5	6	12	13	111	159	142	142
1874	7	6	9	23	151	166	163	143
1875	6	7	9	40	151	165	148	118
1876	5	7	13	12	59	87	93	113
1877	9	10	8	17	128	130	149	137
1878	6	6	26	45	151	179	151	128
1879	7	9	11	94	155	156	152	57
1880	6	9	16	23	86	133	125	87
Average duration	6.4	7.5	13.0	33.4	124	147	140	116

Counting from the date when the mean daily temperature is 5° C. and the wheat begins to sprout to the date when the wheat begins to head, Gasparin adopts 430° C. as the sum of the mean daily shade temperatures. Marié-Davy finds from the date of actual sowing of the seed to the date of heading out a sum of 555° C. after rejecting all daily mean temperatures that are below 6° C. according to the rule of Hervé Mangon. He also finds 639° C. for the sum total of temperatures between the dates of germination and heading out after rejecting all days below 6° C. On this last hypothesis are calculated the duration of the heading stage and the mean dates of heading for the respective years as given in the columns 6 to 9 of this table. These computed dates of heading out show that the sowing of wheat on October 15 or November 1 or 15 brings it to a head at the end of February or beginning of March, but when the sowing occurs on October 1 it is brought to a head so much earlier in February as to expose it to great chance of injury by the frost; for although the grasses and the green wheat plant resist the action of frost, yet the embryo seed in the ear or head does not do so, and if once destroyed by frost will not be replaced unless the soil is very fertile.

The third epoch, or the flowering of the wheat, takes place in France, according to Gasparin, when the mean temperature has risen to 16° C. or when the sum total of daily shade temperatures has amounted to 813° C., counting from the beginning of vegetation in the spring or from the date when the mean daily temperatures is 5° C. in the shade. This figure relates, of course, to an average of many years, and the individual years may vary very considerably. Marié-Davy, as before, adopts the views of Hervé Mangon as to

rejecting all mean daily temperatures below 6° C., and thus finds 1,496° as the mean value of the sum of temperatures from the date of sowing to that of flowering. The similar sum from the date of heading to flowering is 860°, or 1,496° less 639°.

The fourth epoch, or the ripening of the wheat, occurs when the sum total of the mean daily shade temperatures since the date of flowering, rejecting all below 6° C., amounts to 815° C., and in the climate of Paris this occurs about forty-five or forty-six days after the date of flowering. The range of uncertainty in this last interval is only four or five days, owing largely to the uniformity of the climate at this season. It is the best defined of all the periods and so well ascertained that, knowing any actual date of flowering we can safely predict the date of ripening. In proportion as we approach the latter date the process of ripening seems to concentrate itself more and more within the wheat; water and sunlight become less and less important; rain becomes a source of uneasiness as to the harvest, and the intensity of sunshine has only an indirect influence on the quality and quantity of the grain. The influence of sunlight during the first phase or germination is negligible and probably nothing; it is a maximum at the beginning of the fourth phase, but diminishes rapidly as the fourth phase progresses and in proportion as the wheat becomes more yellow. We shall therefore consider the amount of sunshine, or more properly the total radiation from sun and sky, during the first thirty days after flowering and neglect its amount during the remainder of the period up to maturity.

The following table shows the amount of radiation, as expressed by Marié-Davy in actinometric degrees or percentages and computed from actual observations of his actinometer at Montsouris for the various stages of growth, viz, the second or heading stage from germination to heading, the third or flowering stage from heading to flowering, and fourth for the first thirty days of the fourth or ripening stage immediately following the flowering:

Year of sowing.	Total radiation received during heading stage.				Total radiation received during flowering stage.				Total radiation received during 30 days of ripening stage.			
	a.	*b.*	*c.*	*d.*	*a.*	*b.*	*c.*	*d.*	*a.*	*b.*	*c.*	*d.*
1873	842	1,332	1,755	1,848	3,205	2,979	2,870	2,954	1,176	1,608	1,548	1,581
1874	908	1,191	1,663	1,938	3,031	2,933	2,620	2,482	1,403	1,220	1,171	1,194
1875	904	1,009	1,161	1,247	3,214	3,169	3,169	2,821	1,419	1,504	1,526	1,558
1876	652	698	646	811	......	......	......	......	......	......	......	......
1877	733	739	977	1,255	2,096	2,302	2,282	2,208	1,103	1,199	1,399	1,450
1878	800	1,382	1,476	1,743	2,749	2,634	2,630	2,506	1,320	1,496	1,131	1,184
1879	840	1,251	1,582	1,600	3,095	2,580	2,658	2,607	1,076	1,092	1,321	1,362
1880	1,000	1,578	1,924	1,991	3,519	3,106	2,849	2,865	1,391	1,438	1,433	1,486
Average of 6 years	857	1,117	1,497	1,653	2,977	2,808	2,723	2,629	1,268	1,363	1,360	1,363

If we sum up the second, third, and fourth series of figures we finally obtain the sum total of the effective radiation received during the whole interval from germination to ripening, as given in the following table:

Year.	Total radiation received from germination to ripening. a.	b.	c.	d.	Average for Oct. 22.	Relative value of actual crop.
1873	5,223	5,919	6,173	6,383	5,924	25.2
1874	5,342	5,344	5,454	5,614	5,438	19.0
1875	5,537	5,682	5,856	5,626	5,676	26.5
1876	....	....	....	....	....	22.5
1877	3,932	4,240	4,658	4,913	4,436	15.2
1878	4,869	5,512	5,237	5,433	5,263	11.1
1879	5,011	4,923	5,561	5,569	5,266	....
1880	5,910	6,117	6,206	6,345	6,145	....
Average of 6 years	5,102	5,288	5,550	5,645	5,396	....

The relative value of the wheat crops, as observed at two stations, is given in the last column of the preceding table, and the comparison of the figures shows that a deficiency of sunshine has a decided effect in diminishing the relative value of the crop; but the converse is not true, for we may have an excess of sunshine and still get poor crops, owing to a deficiency of rain or irrigating water. In fact, the preceding study only shows the nature of the influence of the solar radiation; the exact quantitative effect on the amount of the crop must vary with the irrigation or rainfall, with the fertilizers applied to the soil, and with the peculiarities of the seed.

As to the rainfall, it was in the preceding cases distributed as shown in the following table:

Year of sowing.	Rainfall during stages. Germinating.	Heading.	Flowering.	Ripening.	Total sunshine from germination to ripening.
1873	1.19	0.75	0.78	1.72	5,924
1875	2.97	1.36	0.99	1.44	5,676
1878	1.84	1.90	1.65	1.94	5,263

From these figures we conclude that the excess of rain in the wheat season of 1878–79, which would have been advantageous with a clear sky, as in Egypt,[a] was at Paris accompanied by too little sunshine, and therefore the crop suffered. For a given quantity of sunshine a certain quantity of water is best for the crop; if the sunshine is diminished the plant can not use so much water, and that must be correspondingly diminished.

[a] Or as in the case of irrigation in the arid portions of the United States.—C. A.

The influence of the date of sowing and its relation to sunshine and frost is fully shown in the table for Montsouris, which gives the sum total of actinometric degrees from the time of germination to maturity for seeds sown on successive weeks in 1879, 1880, and 1881, and harvested in 1880, 1881, and 1882:

Date of sowing.	Total sunshine from germination to ripening (actinometric degrees).	Date of sowing.	Total sunshine from germination to ripening (actinometric degrees).
1879.		1880.	
October 1	5,011	November 24	6,393
October 8	5,144	December 1	6,461
October 15	5,074	December 8	6,529
October 22	5,574	December 15	6,611
November 1	5,561	December 22 [e]	6,504
November 8	5,596	December 29 [e]	6,245
November 15	5,569	1881.	
November 22		January 5	
1880.	([a])	January 12	([f])
February 8		January 19	
February 15	5,622	January 26	6,245
February 23	5,597	February 2	6,018
March 1	5,581	February 9	6,047
	([b])	February 16	6,043
September 29 [c]	5,910	February 23	6,037
October 6 [c]	6,052	March 2	6,037
October 13	6,117	March 9	5,571
October 20 [d]	6,091	March 16	5,286
October 27 [d]	6,118	March 23	5,271
November 3 [d]	6,206	March 30	5,215
November 10	6,204	April 6	5,144
November 17	6,343		

[a] Frozen soil prevented sowing.
[b] No sowing during this interval.
[c] See note 1 in text.
[d] See note 2 in text.
[e] See note 3 in text.
[f] Frozen ground prevented sowing.

Among other conclusions that may be drawn from these figures are the following, most of which are also given by Marié-Davy:

1. The season 1880–81 was characterized by much sunshine and little rain, which hastened the ripening, but delayed the flow of sap, and therefore of nourishment to the grain, so that the crop was rather poor.

2. For the crops of fall wheat the sunshine increased more and more as the seed was sown later from September, 1880, even to the end of December; then it began to diminish, and for the spring wheat, sown in March, 1881, it was too small.

3. By considering other weather records it is evident that the freezing of the ground in January, 1881, not only prevented the sowing of the seed, as noted in our table, but prevented the germination of the seeds sown on December 22 and 29, 1880, which would otherwise have sprouted on February 4 and 19, 1881, respectively.

4. The wheat sown September 29 and October 6, 1880, which headed out December 30 and February 19, was injured as to the heads by the subsequent frost.

5. The seeds sown October 20, 27, and November 3, 1880, flowered between the 4th and 8th of June, 1881, but at this time there was experienced at Paris a spell of very cold weather, the minimum daily temperature being 3.1° C., and even white frosts were reported, so that wheat which was then in flower was badly injured.

6. In general, the dates November 10, 1880, to December 15, 1880, are those indicated as most favorable for sowing wheat in that year, and the crop of 1881 may be predicted as likely to be small, but of excellent quality.

The grape and wine crop.—In a short study on the relation between the vine and the weather, Marié-Davy (1882, p. 290) states that, in general, the annuals, such as the cereals, concentrate all their energy in the formation of the ear and the seed or grain. Their work is then finished and they die. The next year's crop of these annuals is largely under the control of the husbandman, who can obtain seed from more favored regions if his own crop was inferior.

On the other hand, the work of the vine, like all perennials, is not merely to ripen its fruit and seed, but to preserve its own individual self for usefulness in future years. Therefore it elaborates out of its own sap not merely leaves and fruit and seed, but a store of woody fiber. Corresponding to this more complex system of growth the relations of the perennials to the climate are apparently more complex than the relations of the annuals, and, it may also be added, the range of geographical distribution, whether by nature or by cultivation, is more restricted.

Our studies will be confined to the data furnished by the observations at Epernay (1873–1881), to which Marié-Davy adds other data computed from the observations made at Montsouris, in which latter computation certain laws of growth of the vine as established by Gasparin were adopted.

In the neighborhood of Paris the leaf buds of the vine burst open in May when the mean daily temperature has permanently passed above 11° or 12° C. Assuming that the mean of twenty days, as observed at Montsouris, will give this date (which was unfortunately not observed at Epernay), we obtain the figures in the first three columns of the following table. In some of these years the early leaf buds were undoubtedly killed by nocturnal frosts, but they were soon replaced by other buds, and the dates here given must be adopted in the absence of actual observations, especially when we remember that the quantity and quality of the final crop of grapes depend not only

on the meteorological conditions, but, equally or more, on the condition of the woody fiber of the stock and stems. Similarly the date of flowering is calculated by assuming, with Gasparin, that the sum total of the mean daily temperatures in the shade must be 466° C., counting from the date of leafing. This number is more especially applicable to the vineyards of Champagne and Burgundy, and is not necessarily strictly applicable to Epernay or to the vineyards of the south of France. The fifth and subsequent columns of the table give the mean climatic conditions for a period of sixteen days, in the middle of which is the calculated date of flowering. There appears to be no simple relation between this latter data and the resulting wine crop, nor has the crop any apparent relation with the total sky radiation during this period. In fact we may conclude that up to the time of flowering the energy of the vine has been devoted to building up its own structure as a preparation for the work that is to come. The development of the grape does not depend upon nitrogenous particles stored away in the vine, but on the power to elaborate the sap which is to become the juice of the grape, and that power depends upon the leaf surface, the roots, and the stock during the first stages of the growth of the grape, but eventually upon changes that go on within the grape itself.

These facts are brought out by the study of the conditions prevailing during the last stages, viz, from flowering to maturity:

Calculated date of leafing.	During 20 days.		Calculated date of flowering.	During 16 days.		
	Average temperature.	Total rainfall.		Average temperature.	Average radiation.	Total rainfall.
	° C.	mm.		° C.	° Actin.	mm.
May 21, 1873	12.1	25.3	June 22	18.7	46.1	88.1
May 20, 1874	13.2	20.5	June 13	16.8	41.5	26.8
May 9, 1875	16.0	25.5	June 6	19.0	55.2	38.3
May 28, 1876	14.2	3.0	June 25	19.4	49.0	52.3
May 13, 1877	11.5	56.8	June 12	20.9	51.6	18.3
May 16, 1878	14.1	51.7	June 16	16.4	40.3	55.1
May 21, 1879	12.6	35.9	June 22	16.6	43.0	25.7
May 16, 1880	14.0	0.0	June 16	16.2	37.6	45.5
May 21, 1881	14.6	29.0	June 8	14.9	48.7	15.2
Average May 18	13.6	27.5	Average June 16	17.7	45.9	40.6

According to Gasparin the grape reaches its maturity when it has received a sum total of mean daily shade temperatures of 1,926° C., counting from the date of flowering, but the grape ceases to be nourished or to ripen when the mean daily temperature falls below 12.5°. If, now, we ascertain the date of maturity by summing up the daily temperatures, as required by Gasparin's rule, we obtain the results given in the first column of the following table. If we

take the mean values for the twenty days previous to the date of maturity we obtain the data in the second, third, and fourth columns, and we notice that although in the warmer seasons there may be a great variety in the value of the crop, yet in the cold seasons, 1877 and 1879, when the mean temperatures fell below the limit (12.5°) required for ripening, the crop was very poor or failed altogether. If now the total radiation from sun and sky is computed according to Marié-Davy's method for the period between leafing and flowering and again from flowering to maturity we obtain the figures in the columns five, six, and seven. Here we see, as before, that the variation during the flowering period was of little importance, whereas that during the ripening period has a direct relation to the character of the wine crop, such that in general the larger the total radiation the better the crop, provided the temperature of the air has not fallen too low.

Calculated dates of ripening.	During previous 20 days.			Total radiation by stages.			General character of—		
	Mean daily temperature.	Mean daily radiation.	Total rainfall.	Leafing to flowering.	Flowering to ripening.	Sum.	Juice.		Wine crop.
							Sugar.	Acid.	
	° C.	° Actin.	mm.	° Actin.	° Actin.	° Actin.			
October 7, 1873	16.1	30.2	20.3	1,278	4,590	5,868	162	8.2	Excellent.
September 25, 1874	16.0	27.6	28.8	1,343	4,544	5,887	179	6.1	Finest.
September 21, 1875	17.4	40.6	5.9	1,306	4,322	5,728	181	5.4	Good.
October 7, 1876	16.2	27.7	16.7	1,222	4,205	5,427	174	6.8	
October 2, 1877	11.9	30.4	8.2	1,280	4,603	5,883	186	8.7	Very poor.
October 2, 1878	13.3	25.5	23.8	1,238	4,165	5,403	181	6.7	Good.
October 15, 1879	11.5	26.1	6.3	1,355	4,033	5,388	154	9.5	Very poor.
September 29, 1880	15.2	27.8	25.0	1,305	3,966	5,301	188	6.4	
September 26, 1881	15.1	24.2	81.2	1,575	4,262	5,837	180	6.1	Excellent.
Average October 2	14.7	28.9	24.0	1,322	4,302	5,636	176	7.1	

In general, Marié-Davy concludes that the number of grapes to the bunch and the number of bunches to the vine do not seem to have any clear relation to meteorological conditions, except in the case of spring frosts, which can destroy a crop. Besides the conditions as to pruning the vine and dressing the soil, the number of grapes that have set (on which principally depends the quantity of the crop that will be produced) is a result primarily of the meteorological conditions during the previous year and of the state of preparation of the woody stock. On the contrary the final size of the grapes and the quality of the juice depends on the meteorological conditions of the crop year and those that accompany the flowering and succeed it up to the time of maturity. A final sum total of radiation is not sufficient; it is necessary to take account of its distribution with reference to the

phenological periods and of other accompanying circumstances. Thus in 1877, with a low mean temperature and a high radiation during maturity, and in 1879, with a low temperature and a low radiation during the last phase, both alike gave a poor crop, but the sunshine of 1877 was able to make a large quantity of sugar as compared with the small quantity of sugar in 1879.

Sugar beets.—Marié-Davy (1882) and Pagnoul (1879) give the data of a research into the relation of climate to the development of sugar beet as cultivated at Arras, the agricultural station of the Department of Pas de Calais. The following table gives the results of meteorological observations and chemical analyses of sample beets taken up every ten days during the season. The beets were sown April 5, 1879, averaging six plants to the square meter. They were of a poor variety, but of the kind ordinarily planted in that section; they were of a rosy color, and were planted a great distance apart in order that they might grow more rapidly.

Decade ending 1879.	During the decade.				At end of decade.				
	Total rain.	Total heat (sum of mean daily shade temperatures).	Total sunshine (daily average of clear sky).	Total radiation (sum of daily actinometric degrees at Montsouris).	Average weight of— Root.	Average weight of— Leaves.	Average density of juice.	Weight of sugar per 100 beets.	Weight of sugar per hectare.
	mm.	*° C.*	*Per cent.*	*° Actin.*	*Kilos.*	*Kilos.*	*Beaumé.*	*Kilos.*	*Kilos.*
June 11	33	156	41	393	1	8	2.9	3.03	2
June 21	37	162	30	479	7	41	2.8	2.13	9
July 1	18	159	31	444	31	110	3.3	5.18	96
July 11	56	138	16	399	105	222	3.5	5.38	339
July 21	59	165	26	320	220	333	3.2	5.88	776
July 31	26	158	28	378	346	462	3.9	6.85	1,422
August 10	8	179	31	416	486	452	4.0	6.33	1,848
August 20	24	182	43	361	666	433	4.2	7.69	3,073
August 30	18	177	36	373	778	335	4.1	7.57	3,534
September 9	4	159	56	385	878	312	4.4	8.20	4,320
September 19	27	165	34	326	1,040	200	4.3	7.46	4,655
September 29	10	131	49	251	1,048	126	4.1	7.46	4,691
October 9	5	129	25	334	1,048	194	4.4	8.06	5,068
October 19	18	95	12	161	1,056	98	4.1	7.46	4,727
October 29	23	87	26	144	1,050	128	4.5	7.94	5,002

The influence of sunshine is to be found by studying the fourth column of the sum total of daily average cloudiness at Arras, as resulting from twelve daily observations of the amount of cloudiness. The clearness of the sky, as given in the fourth column in percentages, is

the complement of the cloudiness and represents the relative duration of sunshine, but owing to the varying altitude of the sun can by itself alone give no idea of the intensity of the radiation received by the plant. To obtain this last item and as no actinometric observations were made at Arras I give in the fifth column the results of observations at Montsouris, expressed in actinometric degrees.

The beets are reported to have sprouted very late and very unequally; this was due not to dryness, since the rain during March and April was in excess of its normal value, but was directly traceable to the low temperature, which was especially low in April.

The study of the development of sugar, week by week, as given in the last two columns of the above table shows that after September 9 the sugar crop increased slowly, became stationary, and then fluctuated very much as the weight of the leaves fluctuated. The rainfall had at that time become light and the development of the beet seemed to depend mostly on the temperature, so that it may be concluded that the beet ceases to increase in its quantity of sugar after the mean daily temperature falls below 13.1° C., and that there is no probable advantage in leaving the beets in the soil after that date, which in this case is September 29, 1879.

Marié-Davy points out that the actual increase per decade of the weight of the roots coincides with the increase of the rainfall and the temperature, but the proportion of sugar increases with the degree of radiation or total sunshine; the sunshine precedes the formation of sugar, since its action is slow and indirect, being through the assimilation that takes place within the leaves. It is therefore not an excess of water, but a deficiency of light and heat that causes rainy autumns and summers to give poor crops of sugar. Therefore, if during dry, clear, warm summers having large radiation, one could irrigate the fields properly one would realize the best conditions for a good crop. Therefore, every ray of sunshine that strikes the ground instead of the leaf is a loss to the formation of sugar and by helping to evaporate the moisture of the soil it also causes further great loss of sap to the plant. These conclusions agree with other experiments made by Pagnoul, who raised beets both in darkness and under a transparent bell glass, and again in the free air, and found the amount of sugar to increase with the strength of the sunshine.

The following table gives a general survey of the beet crops in Pas de Calais and the corresponding climatic data at Montsouris, which is about 90 miles south of Arras. The numbers given in the columns for quantity and quality of the crops are the estimates obtained from many planters and are recorded on the following scale: 1, very small

or very bad; 2, small or bad; 3, passable or mediocre; 4, fairly good; 5, good; 6, very good.

Year.	Dates when mean temperature of air thermometer in shade—		Duration beet root season.	During the season.			General character of sugar crop in Pas de Calais.		
	Rises above 9° C.	Falls below 13° C.		Sum of mean daily air temperature.	Sum of mean daily radiation.	Total rainfall.	Quantity.	Quality.	Density of juice.
			Weeks.	*° C.*	*° Actin.*	*mm.*			*Beaumé.*
1873	Mar. 23	Oct. 12	29	3,079	....	393	4	5	5.3
1874	Mar. 16	Oct. 19	31	3,389	8,963	264	5	3	4.6
1875	Mar. 30	Oct. 5	27	3,172	7,900	313	6	3	4.2
1876	Mar. 23	Oct. 19	30	3,003	8,539	299	1	1	3.9
1877	....do...	Sept. 21	26	2,786	7,326	344	4	6	5.5
1878	Apr. 6	....do...	24	2,791	6,552	347	5	3	4.7
1879	Apr. 20	....do...	22	2,359	5,815	278	1	3	4.4
1880	Mar. 2	Oct. 11	32	3,132	8,410	280	....	....	....
1881	Apr. 6	Sept. 28	25	2,520	6,369	340	....	....	....
Average	Mar. 26	Oct. 4	27	2,915	7,484	306	....	....	....

The climatic data given in the above table as directly applicable to the seasons of growth of the beet root illustrate what should be given for any similar study of development of any crop. But it is commonly the case that the dates of the various phenological epochs are not exactly given, and that we have to rely upon general tables of general climatic conditions month by month, such as are recommended by the International Meteorological Congress of Vienna and by that of Rome. Therefore, for the sake of comparison with other climates whose data are given on the so-called international forms, I give in the following table a part of Pagnoul's tables of average temperature Centigrade and rainfall in millimeters as observed at Arras:

Year.	Mean daily shade temperature.							Total monthly rainfall.						
	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
1873	8.6	11.0	16.7	19.1	18.2	13.5	9.9	48.6	45.5	63.3	26.2	40.3	33.5	56.1
1874	11.0	11.4	16.6	20.1	17.0	15.5	11.0	20.7	32.9	25.7	16.0	34.2	92.3	47.2
1875	9.6	14.7	16.7	17.4	19.1	16.6	9.0	8.0	30.7	82.0	63.7	62.0	74.5	61.6
1876	9.3	14.8	16.7	19.6	19.3	13.9	12.1	41.3	15.3	32.0	23.8	87.3	87.0	24.5
1877	8.8	11.3	19.1	17.8	17.7	12.3	9.7	45.0	88.2	23.0	61.2	96.5	50.3	48.5
1878	16.3	14.2	17.2	18.0	18.6	14.9	10.6	53.7	88.4	60.6	46.7	86.6	42.9	87.3
1879	7.6	10.6	15.9	15.5	17.6	15.1	9.8	48.4	51.7	138.6	142.0	50.5	39.5	45.4

The preceding study gives a first idea as to the relation between climate and the development of the leaves, the roots, and the sugar, and offers a first step toward determining how suitable for the beet-sugar industry any climate may be, and especially does it suggest to

the planter how he may early in August begin to safely predict from week to week what his probable crop will be early in October. Thus, table on page 259 shows, by the samples taken August 20, that there were then in the beets 3,073 kilograms of suger per hectare, whereas on October 9 there was 5,068, or five-thirds of that present on August 20. This factor, five-thirds =1.67, is, therefore, that by which the figures of August 20 are to be multiplied in order to obtain those of October 9. The following table gives similar factors for the successive decades for the crop of 1879, and when a succession of years has been thus treated we shall know something of the accuracy with which the harvest crop can be predicted. The regularity with which these numbers run shows that after the 1st of September the error of prediction can only be a small per cent.

Date of sampling (1879).	Crop factor for this date.	Weight of sugar.
August 10	2.74	1,848
August 20	1.65	3,073
August 30	1.43	3,534
September 9	1.17	4,320
September 19	1.09	4,655
September 29	1.08	4,691
October 9	1.00	5,068

Pagnoul calls attention to the fact that the roots contain a considerable portion of nitrates, although the soil in which they grow had not received during this or previous years a trace of these salts. This salt could only have come into existence by the nitrification of organic nitrogenous matter, and it is well to insist upon this fact, for we can thus remove from the minds of certain persons the idea that if the beet root contains nitrates they must have been put into the soil by the cultivator. This mistake has frequently caused unhappy contests between the farmer and the sugar manufacturer.

If the beet root had at its disposal only a proper proportion of nitrates that had been formed in the soil before sowing, these salts would be rapidly absorbed; they would by their decomposition give rise to a large and prompt development of leaves, and, consequently, to an easier elaboration of sugar, and in proportion as vegetation advances we should find smaller quantities of nitrates in the beets. This fact was proven by Marié-Davy in 1878.

If on the contrary the nitrogen is furnished by a process of nitrification that is prolonged during the whole season, then the absorption of the nitrates goes on continuously and their total weight per hectare increases steadily to the end of October, as shown in these analyses for 1879.

Some further experiments by Pagnoul (1879, p. 486) on the beet as grown in darkness and in sunshine shows that the former were exceptionally rich in alkali, ash, and especially the nitrates. This is explained as above, viz: The nitrates will not decompose within the plant except under the influence of sunshine; if the plant is kept in darkness it stores up the nitrates within itself without having the power of utilizing its own nitrogen, so that the substances in the formation of which this nitrogen ought to be of assistance can not be formed.

From this one must conclude that years that are bad for the beet-sugar crop are so not only because of unfavorable temperatures and humidities but above all because of a defect in the insolation. Lively complaints have been made of the quantity of nitrates in certain harvests; now these salts that accumulate in the molasses and in the inferior products and augment the difficulty of the work occur often in beets cultivated upon a soil that has never received a trace of nitrates as a fertilizer. It is therefore not to the abuse of nitrates as a fertilizer that we ought to attribute their presence, but rather to a too cloudy sky.

We know that the neighborhood of large trees is injurious to the vegetation around them. Ordinarily we attribute this injurious influence to their roots. It would perhaps be more exact to attribute it to the shade that they cast, and the more so because it has been demonstrated by Cailletet that green light has no power to bring about the decomposition of carbonic acid.

In the Annuaire for 1883 Marié-Davy studies the influence of the date of sowing. In order to ascertain the best dates for sowing and trace out the various vicissitudes to which the crop is subject, whether resulting from the climate as such or from the ravages of insects or fungi, it is necessary to make a rather detailed study of the state of development of the plant under the assumption that the seeds were sown on successive dates—for instance, on a given series of successive week days. An elaborate study of this kind is given for wheat by Marié-Davy (pp. 244–285 of his Annuaire for 1883), from which the following tables have been extracted. In general the varieties of wheat cultivated in the south of Europe are more sensitive to cold than those of the north, but the studies of Marié-Davy for the latitude Montsouris, when paralleled by similar studies for localities in the United States, can but be of the greatest value both to the farmers and the statisticians of this country. The study of such tables will enable one to very closely predict the time of harvest, the quantity and quality of the crop, and the range of uncertainty. To this end it is, of course, understood that corresponding elaborate tables of

meteorological conditions must be accessible, samples of which I have prepared for twenty United States stations.[a]

If we suppose some wheat to have been sown on the 22d of September, 1871, near Paris, and if we adopt the rule established by Gasparin that the vitality of the seed is actively aroused as soon as its temperature in a moist earth exceeds 5° C., and that it germinates visibly when it has received a sum total of mean daily temperatures that is equal to 85° C., and that the sprout rises above the surface of the earth in a few days after the seventh, then we obtain six days as given in the following table for the interval from sowing to germination. A similar computation for every other date of sowing, as given in the following table, shows at a glance the effect of the temperature of the soil on this phase of plant life.

Duration, in days, from sowing to germination of winter wheat at Montsouris, France, for the years 1872–1881.

Date of sowing.	1871.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	Germination.	
												Average duration for the years 1872–1881.	Average date.
September 22	6	7	7	5	5	7	8	7	7	6	6	7	Sept. 29
September 29	7	7	5	7	6	6	8	7	7	7	10	7	Oct. 6
October 6	8	9	7	7	9	5	8	7	8	7	8	8	Oct. 14
October 13	8	8	9	6	8	7	10	7	10	10	11	8	Oct. 21
October 20	12	8	13	10	11	11	5	7	9	22	15	11	Oct. 31
October 27	70	8	13	9	11	16	8	29	14	18	13	20	Nov. 16
November 3	72	15	15	14	8	12	8	25	16	14	7	20	Nov. 23
November 10	77	15	17	32	8	8	14	48	98	9	10	33	Dec. 13
November 17	70	9	12	49	41	13	12	44	93	21	10	36	Dec. 23
November 24	63	10	25	53	42	11	25	39	89	17	26	37	Dec. 31
December 1	56	16	43	48	35	8	46	69	82	12	42	42	Jan. 12
December 8	49	16	36	42	28	22	67	62	75	11	67	41	Jan. 18
December 15	42	12	25	35	21	12	60	55	68	13	60	35	Jan. 19
December 22	35	11	30	28	56	14	55	48	61	43	57	38	Jan. 29
December 29	28	19	26	21	53	9	49	42	53	44	50	34	Feb. 1

In studying the preceding table we recall that the duration of germination varies slightly with the condition of the soil and the depth of the grain below the surface; these two considerations will be perfectly allowed for if we observe directly the temperature of soil by a buried thermometer. Such observations are earnestly recommended to all agricultural experiment stations, as they are, evidently, more directly applicable to the growth of plants than any crude

[a] These tables are omitted in the present edition.

approximations derived from the observation of the temperature of the air only. If when the grain has sprouted the soil continues very dry, the nourishment having all been drawn from the seed, the young plant may droop and die. If, again, the frost penetrates to the seed while it is germinating, many of the seeds will perish, and the field will appear as if sparsely sown, but this latter mishap is generally repaired by nature if the soil is good and the springtime favorable, for the sowing is generally in excess and the extra heading will supply the loss of the seeds that have perished, but in poor soil the harvest will be notably diminished, and often it will be profitable to plow the soil for a new sowing.

In any case the chances for a successful crop vary very much with the date of the sowing, as we shall see by the study of the following table, which shows that in each year the season for sowing that is favorable to the crop of that year is very much restricted by the early arrival of the winter cold. Thus in 1871 the sowing was stopped on the 20th of October by the cold weather; in 1872 it continued throughout the autumn until the 29th of December; in 1880 it occurred on the 3d of November. Sometimes heavy rains prevent the sowing, but in 1881 neither cold nor rain prevented field work until the middle of December. [In order to save space I have omitted the elaborate tables of frosts, low temperatures, and rains given by Marié-Davy for each of these years and weeks.—C. A.]

The grain now arrives at the epoch of heading, at which the original stalk becomes several branches, each of which bears an immature head on which the rudimentary seed can already be counted under the microscope; the number of such seeds will not increase in the further development of the plant, but many of them may not come to maturity; therefore a careful count of these rudimentary seeds over a small area of the field would give a first estimate of the maximum possible crop.

According to Gasparin the length of time that elapses from the moment when the mean daily temperature of the air in the shade is 5° C. up to the date of heading of the wheat is such that the sum total of the mean daily shade temperatures is 430° C., but as the initial date is difficult to determine we shall in our calculations adopt the rule of Hervé Mangon, according to whom the sum of the mean daily temperature in the shade, rejecting all that are below 6° C. (at which the wheat does not vegetate), is 640° C. if we count from the date of sowing, or 555° C. if we count from the date of germination. The following table is computed by counting from the former date; a parallel computation from the latter date shows that on the

average of ten years there is no appreciable difference between the results.

Duration, in days, from sowing to heading of winter wheat, at Montsouris, France.

Date of sowing.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	Average for 1872–1881.	
												Duration.	Date.
September 22	152	67	87	58	91	57	61	167	160	85	154	99	Dec. 30
September 29	158	72	116	113	147	64	110	171	161	92	159	120	Jan. 27
October 6	161	80	161	155	153	84	135	180	161	136	157	141	Feb. 24
October 13	168	90	164	172	164	88	140	173	164	147	155	147	Mar. 9
October 20	168	133	163	175	163	107	138	178	164	148	150	154	Mar. 23
October 27	163	140	162	174	160	106	145	185	164	147	152	155	Mar. 31
November 3	162	141	158	172	156	107	156	182	162	141	146	154	Apr. 6
November 10	155	140	158	171	159	108	156	175	158	128	146	151	Apr. 10
November 17	148	134	153	165	156	123	150	168	153	141	144	149	Apr. 15
November 24	141	134	148	159	160	125	147	162	147	135	141	145	Apr. 18
December 1	134	136	142	154	143	123	143	156	140	131	136	140	Apr. 20
December 8	127	132	135	148	136	120	138	149	133	127	129	135	Apr. 22
December 15	120	126	128	141	129	115	131	142	126	124	122	128	Apr. 22
December 22	113	129	121	134	124	111	126	135	119	126	118	124	Apr. 25
December 29	106	127	114	127	120	106	120	131	112	123	111	118	Apr. 26

This table shows that on the average of ten years the seed that was sown, e. g., on the 27th of October and required one hundred and fifty-five days to head, is that which took the longest time; for sowings before that date, as well as after it, the durations steadily diminish; in other words, this sowing is that whose development was the most retarded by the winter cold. If we compare this table with those given by Marié-Davy, showing the frosts, we find a complete inversion in the chances of injury from frost; wheat as a green plant has as little to fear from frost as has the dry grain. But during and after the formation of the embryo seed, as well as during germination, on the contrary, frost is very injurious, and if the embryo is seized by frost it perishes. If this accident occurs it is possible that the progress of heading may permit a new formation of embryo to replace those which have perished. Such accidents must have occurred to the seed sown in the hope of reaping an early harvest in 1874, 1875, 1876, 1877, 1878, and 1881, but did not occur in 1882. This accident is not incompatible with an excellent harvest, as we see in the case of 1874, but it causes a decided retardation of the harvest, as in 1877. The mean of the ten years shows that the heading occurs at an epoch in the spring when the mean temperature of the air is between 6° and 13° C., and when the rainfall is generally abundant, so that at this epoch damage does not generally occur to the grain; only in case of the sowing of September 29, 1878, did the

heading occur during the very cold season likely to be injurious to vegetation.

We pass now to the period from the heading of the wheat to the flowering. According to the determination of Herve Mangon, the sum total of the mean daily air temperatures in the shade necessary to flowering is 1,500° C., counting from the date of sowing, or 860° if counted from the date of heading. If we consider the date thus fixed for the flowering we shall find that it corresponds to a mean daily temperature at that epoch of 16.5° C. on the average of many years; but if we consider the individual years we shall find the actual mean temperatures of that date to vary from 8° to 22° C., and also that for temperatures below 13° the flowering becomes uncertain, prolonged, and detrimental to the crop; but as to the upper limit, 22° C., there is no evidence that even higher temperatures will be injurious. The following table gives the calculated number of days that elapse from the sowing to the flowering, together with the average duration and the corresponding average date. The corresponding tables of mean temperatures and lowest temperatures at the date and the quantity of rainfall are omitted for want of space.

Duration in days from the sowing to the flowering of winter wheat at Montsouris, France.

Date of sowing.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	Average for 1872–1881.	
												Duration.	Date.
September 22 ...	244	228	239	237	238	208	231	261	242	235	239	236	May 16
September 29 ...	243	226	237	238	242	209	229	259	239	235	239	236	May 23
October 6	242	220	237	238	243	214	227	258	238	233	235	235	May 29
October 13	241	225	234	234	240	217	222	251	236	231	232	233	June 3
October 20	238	225	231	231	237	219	216	249	234	229	225	231	June 8
October 27	232	222	226	226	232	215	210	249	232	224	222	227	June 12
November 3	228	219	220	220	227	212	217	245	227	219	215	223	June 14
November 10 ...	221	217	218	218	223	206	215	238	223	214	214	219	June 17
November 17 ...	214	211	212	212	219	203	209	231	217	211	212	214	June 19
November 24 ...	207	207	208	208	213	198	206	224	211	205	208	209	June 21
December 1......	200	203	202	202	206	191	202	218	204	199	202	203	June 22
December 8......	193	200	195	195	199	188	197	211	197	195	196	197	June 23
December 15....	186	194	188	188	192	184	190	204	190	191	189	191	June 24
December 22....	179	189	181	181	186	177	183	197	183	186	183	184	June 24
December 29....	172	185	178	178	180	171	176	191	176	181	176	179	June 26

The ripening of wheat is perfected when the plant has received a sum total of mean daily air temperatures in the shade of 815° C. since the date of flowering. This result happens on the average of Paris forty-four days after flowering, and the individual irregularities scarcely ever exceed four or five days. Therefore the date of flower-

ing can be made the basis of a very close estimate of the date of ripening.

The date of flowering occurs at the time of the greatest vital activity of the plant, which at that time is actively drawing its nourishment from the soil and is transpiring, assimilating, and increasing in weight. But very soon this work is relaxed and is confined more and more to the interior of the plant, conveying into the seed the elaborated materials formed within the leaves and stems. It is especially in this latter part of the life of the plant that the internal consumption can exceed the gain from without, and the plant tends to diminish its dry weight.

This period has a great influence on the final result, not only because the plant can gain as a whole, but especially because of the distribution which is made within it of the material which it has brought together. The straw has only a secondary value. It is the seed which constitutes nearly the whole value of the harvest. Therefore all that passes from the straw to the grain is a benefit, though this passage should be accompanied by a notable consumption of the nutritious materials of the stalk. It is neither the state of preparation of the stalk, nor the heat, nor the radiation, nor the moisture which of itself alone produces the best quality of grain. There must be a reunion of all these various elements in a proper proportion, which latter will vary with the weather and with the locality even with the same weather. The blighting of wheat is an accident that one dreads most at this period. The blight, properly so called, is due to a temperature and a radiation that is too intense for the movement of the sap in the plant; the seed has not time to receive the sum total of the nourishing particles that have been prepared for it; therefore it becomes small, lean, and shriveled up. A greater sum total of moisture in the soil or a less active transpiration would have given a better result. But we often confound the blight, properly so called, with the analogous result produced by an insufficient assimilation or elaboration of the various materials that go to make up the wheat grain or by a disproportion in the relative quantities of the elements that should make up the seed.

The following table shows the number of days elapsing from sowing to ripening for the dates adopted in the previous tables. It is calculated by first ascertaining the number of days elapsing from flowering to ripening according to the rule above given and then adding these intervals to those already calculated for the flowering.

Duration, in days, from sowing to ripening, for winter wheat at Montsouris, France.

Date of sowing.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	Average for 1872–1881.	
												Duration.	Date.
												Days.	
September 22	291	282	284	285	287	268	281	311	292	285	290	287	July 6
September 29	290	279	287	285	287	264	279	308	293	284	289	286	July 12
October 6	287	277	279	284	285	263	275	306	286	281	285	282	July 15
October 13	283	274	276	281	281	263	272	299	282	277	281	279	July 19
October 20	279	271	272	280	277	262	268	296	279	273	276	276	July 23
October 27	272	267	269	276	272	258	265	296	275	267	271	272	July 26
November 3	269	263	265	272	266	255	261	290	271	261	264	267	July 28
November 10	262	260	259	269	262	249	258	283	266	255	263	262	July 30
November 17	255	254	255	263	257	245	252	276	260	252	259	257	Aug. 1
November 24	248	249	249	257	250	240	248	270	254	247	254	251	Aug. 2
December 1	241	244	242	251	243	234	243	263	247	241	258	245	Aug. 3
December 8	234	240	235	245	236	232	234	256	240	235	241	239	Aug. 4
December 15	227	234	228	238	229	231	232	249	233	231	234	233	Aug. 5
December 22	220	229	221	231	225	226	225	242	226	226	229	227	Aug. 6
December 29	213	226	217	224	219	220	218	236	219	220	222	221	Aug. 7

In the following table I present a summary of the preceding details, showing the average duration and dates for the ten years from 1872 to 1881, inclusive. To this I have added the average total daily radiation for crops sown in 1873 to 1880, as computed by Marié-Davy in actinometric degrees for two phases, viz, from heading to flowering, and for thirty days after flowering, which brings us through the greater and more important part of the ripening phase.

Summary of dates and radiation for winter wheat during ten years, 1872–1881, at Montsouris, France.

Date of sowing.	Average interval from sowing to—				Average date of germination.	Average date of heading.
	Germination.	Heading.	Flowering.	Ripening.		
	Days.	*Days.*	*Days.*	*Days.*		
September 22	7	99	236	287	Sept. 29	Dec. 30
September 29	7	120	236	286	Oct. 6	Jan. 27
October 6	8	141	235	282	Oct. 14	Feb. 24
October 13	8	147	233	279	Oct. 21	Mar. 9
October 20	11	154	231	276	Oct. 31	Mar. 23
October 27	20	155	227	272	Nov. 16	Mar. 31
November 3	20	154	223	267	Nov. 23	Apr. 6
November 10	33	151	219	262	Dec. 13	Apr. 10
November 17	36	149	214	257	Dec. 23	Apr. 15
November 24	37	145	209	251	Dec. 31	Apr. 18
December 1	42	140	203	245	Jan. 12	Apr. 20
December 8	41	135	197	239	Jan. 18	Apr. 22
December 15	35	128	191	233	Jan. 19	Apr. 22
December 22	38	124	184	227	Jan. 29	Apr. 25
December 29	34	118	179	221	Feb. 1	Apr. 26

Summary of dates and radiation for winter wheat during ten years, 1872–1881, at Montsouris, France—Continued.

Date of sowing.	Average date of flowering.	Average date of ripening.	Average total radiation, in actinometric degrees, 1874–1881.		
			Flowering stage.	Ripening stage.	Sums.
September 22	May 16	July 6	2,562	1,344	3,906
September 29	May 23	July 12	2,681	1,308	3,989
October 6	May 29	July 15	2,840	1,276	4,116
October 13	June 3	July 19	2,817	1,341	4,158
October 20	June 8	July 23	2,751	1,380	4,131
October 27	June 12	July 26	2,735	1,385	4,120
November 3	June 14	July 28	2,739	1,388	4,127
November 10	June 17	July 30	2,731	1,400	4,131
November 17	June 19	Aug. 1	2,705	1,426	4,131
November 24	June 21	Aug. 2	2,704	1,427	4,131
December 1	June 22	Aug. 3	2,668	1,438	4,106
December 8	June 23	Aug. 4	2,678	1,442	4,120
December 15	June 24	Aug. 5	2,690	1,438	4,128
December 22	June 24	Aug. 6	2,613	1,432	4,045
December 29	June 26	Aug. 7	2,595	1,423	4,018

On the average the wheat sown October 13 and ripening July 19 received the most sunshine during the last two stages and should give the best crop.

The preceding study gives the details of the weather and the development of the wheat from 1872 to 1882. Marié-Davy compares these figures with the annual reports of the total crops actually gathered in the Department of Seine-et-Oise, immediately surrounding Montsouris, as shown in the following table, assuming that the crop ripened at any time between July 6 and August 7 during those years.

Wheat crops and sunshine at Montsouris.

Year of harvesting.	Crop hectoliters per hectare.	Total actinometric degrees during flowering and ripening stages.	Year of harvesting.	Crop hectoliters per hectare.	Total actinometric degrees during flowering and ripening stages.
1872	31.0		1880 *	24.4	4,154
1873	17.3		1881 *	24.6	4,351
1874 *	28.9	4,494	1882 *	26.8	3,941
1875 †	21.9	3,892			
1876 *	25.0	4,416	* Average of 5 good years	25.9	4,284
1877 †	23.0	4,140	† Average of 4 poor years	20.4	3,827
1878 †	19.4	3,584			
1879 †	17.9	3,708			

If we summarize the five years of crops above the mean and the four years of crops below the average, as indicated in the preceding

table, there results an apparent confirmation of our view that the radiation during the flowering and ripening phases has an important, direct influence; in fact, the diminution of the average sunshine from 4,284 to 3,827 actinometric degrees has been accompanied by a diminution of the crop from 25.9 to 20.4 hectoliters per hectare. This diminution of 25 per cent of the crop corresponds to a loss of about 1.2 hectoliters per hectare, or 4 per cent of the normal crop, for every 100 actinometric degrees.

We have already seen that if we suppose the same number of stalks to the hectare and the same relative total sum of solid nutriment taken from the soil by each stalk, then, according to theory, the radiation can serve as a measure of the possible work of assimilation by the plant, and consequently of the actual sum total of the assimilated material. These conditions are never completely realized for many reasons, and one can not hope for an exact relation between the crop and the radiation, but it is interesting to see that the above-reported crops, both in detail and general averages, confirm the theory.

Some of the minor departures from perfect agreement are explained by a detailed examination of the conditions during the successive phases of germination, heading, flowering, and ripening during the good years and the poor years. The following table gives the average climatic conditions during the first three phases and shows that as between the good and bad years there can have been but slight average differences in the condition of the stalks and the embryo seeds up to the beginning of the ripening stage, as far as it depends on climatic conditions.

Comparison of climates during five good and four poor years.

Stage.	Good years.	Poor years.
Germinating period:		
Duration .... days..	28	23
Freezing weather .... days..	11.6	9.0
Average minimum temperatures .... ° C..	− 4.66	− 3.7
Rainfall during the period .... millimeters..	9.4	11.6
Heading period:		
Duration .... days..	114	113
Freezing weather .... days..	5.7	6.1
Average of the minimum temperatures .... ° C..	− 1.7	− 2.1
Average temperature at the epoch of heading .... ° C..	10.1	9.7
Average rainfall at the epoch of heading .... millimeters..	14.8	22.1
Flowering period:		
Duration .... days..	75	80
Mean daily temperature at the epoch of flowering .... ° C..	16.3	16.3
Average rainfall at the epoch of flowering .... millimeters..	26.3	31.6
Average radiation during this period .... Actinometric degrees..	2,826	2,525
Ripening period:		
Average radiation during this period .... Actinometric degrees..	1,458	1,302

The preceding table shows that the only important difference between these good and poor years consists in the fact that the latter have more rain and less sunshine. The influence of the temperature of the air as such and of the number of days of freezing weather does not seem to be important, so that we must conclude that the cloudy weather which accompanies the rain and cuts off the sunshine, affects the plant unfavorably only by this loss of radiation. A deficiency of light is more unfavorable than excessive moisture in the soil. In general in France, and especially in dry countries such as the arid regions of America, it is the deficiency of water in the soil that affects the crops unfavorably. Where an abundance of sunshine exists the wheat plant can utilize more water than ordinary soils possess; hence the great advantage of irrigation, as long since practiced in Mesopotamia, Egypt, China, India, Arizona, and South Africa. The numerical data with regard to the quantity of water and the times of irrigation have been approximately determined at agricultural experiment stations, with results given in the next section of this present report.

In the Annuaire for 1890 Marié-Davy gives climatic tables especially adapted for phenological study.

In order that meteorological data may be presented in form convenient for the comparison of crop reports or for the prediction of the future development of the current crop or for other studies in the growth of plants it is necessary that the data should be compiled in a manner very different from that ordinarily given in climatological tables. The monthly means and other data given in the so-called international form recommended and urged by the recent international conferences of Europe have much more regard to dynamic meteorology and to questions in hygiene than to questions in agriculture. For our agricultural studies a continuous summation must be made from the beginning to the end of the year, either by decades, by weeks, by pentads, or even by days for each successive year. From such tables we can calculate the total work that has been done upon the plant by the sunshine and the work that remains to be done before the harvest. Such tables can be compiled in an empirical approximate way from the data furnished by the international forms, as I have attempted to do in table—.[a] But it is far better to prepare them from the original records, and they must be prepared for every agricultural experiment station in the United States before we can profitably study the influences of our

[a] This table is omitted in the present edition.

climates upon our crops. These tables must include at least the following data:

1. The mean temperature of the air in the shade. This may be deduced most simply from the average of the daily maximum and minimum temperatures.

2. The mean temperature of a thermometer, preferably a black bulb, but not in vacuo, exposed to the full sunshine and wind and placed amid the foliage of the trees or the blades of the grain that is to be studied, so that its temperature may be approximately that of the plant. This should also preferably be obtained by using maximum and minimum thermometers.

3. The temperature of the soil at depths of 1 inch and 6 inches, corresponding to the depths of the roots of the plants.

4. The hygrometric condition of the free air, which may be expressed either as relative humidity or as dew point or as vapor tension. The latter will be most convenient in all our calculations.

5. The velocity of the wind or its daily movement.

6. The cloudiness of the sky. This may be obtained from the ordinary estimates of cloudiness if these are made very frequently, but with more ease and accuracy from some form of sunshine recorder.

7. The total effective radiation from sun and sky. This may be obtained from frequent observations of the Marié-Davy actinometer or the so-called Arago-Davy conjugate thermometer, or Violle's conjugate bulbs, but still better when these are made self-recording, and better yet from such forms of apparatus as the photantitupimeter or phantupimeter of Marchand, or the radiometer of Bellani, which Marié-Davy has improved upon in the form described by him as the vaporization lucimeter. (See Annuaire de Montsouris, 1888, p. 207, or 1890, p. 61.) The methods of using these instruments are doubtless subject to improvement, but these or some more delicate substitutes are absolutely necessary in order to enable us to appreciate the work done by solar radiation. In the absence of instruments we may use the maximum sunshine as diminished by the estimated cloudiness.

8. The actual evaporation from plants and soils, or in lieu of this the evaporation recorded by the Piche or even older forms of evaporimeters whose records are doubtless closely parallel to those of the plants in the soil, but usually largely in excess of these.

9. The total rainfall as measured by the ordinary rain gauges in the experimental field.

As an illustration of the convenience of such tables I have compiled the following table for Montsouris by pentads in so far as the data is given by pentads by Descroix in the Annuaire for 1890. Some of the data is obtained by interpolation from monthly values

and some columns are left blank to show that they are still desirable.[a] The pentads or decades to be used in such a table as this should always be those introduced by Dove, the limiting dates of which are as given in this table; the twelfth pentad of the ordinary year has five days, but that of the leap year has six days, so that the limiting dates are always as here given, viz, from February 25 to March 1, inclusive. The data given by Descroix in the Annuaire for 1890 consist of the mean values for the respective pentads. From these I have constructed the sum totals from January 1 to date, which are needed in agriculture, and which are still more easily obtained when we have the original tables of observations at hand, by simply taking the sums in a continuous series and avoiding the labor of computing the means. From such a table of sum totals we obtain the sum between any two dates by subtracting the sum for the earlier from that for the later date.

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[a] The omitted columns are: (1) Sunshine; actual duration. (2) Actinometric degrees; actual daily average. (3) Ratio of actual actinometric degrees to the maximum possible daily average. (4) Soil temperature at the surface. (5) Soil moisture. (6) Percentage of saturation.

Data, by pentads, for Montsouris, 1889, as published by Descroix or specially computed.

Dove's pentad limits.	No.	Sun's location.		Sunshine.		Actinic degrees—maximum possible.		Shade temperature.		Sun temperature (daily maximum).	Relative humidity.	Vapor tension.	Hourly wind velocity.	Total daily evaporation.	Total rainfall.
		Dec'l.	Zen. distance.	Maximum duration.	Average cloudiness.	Noon.	Daily average.	Daily mean.	Daily maximum.						
1889.		°	°	h.	Tenths.			°	°	° C.	P. ct.	mm.			mm.
January 1-5	1	−22.7	71.5	8.3	1	66.7	31.7	−1.0	+1.1	3.2	70.0	3.10	12.4	Frozen	0.0
January 6-10	2	−22.0	70.8	8.4	4	67.7	32.5	+0.6	4.5	6.4	77.6	4.26	9.5	Frozen	9.1
January 11-15	3	−21.2	70.0	8.6	10	68.4	33.4	1.2	2.1	3.2	81.7	4.18	13.7	Frozen	5.4
January 16-20	4	−20.2	69.0	8.8	7	69.5	34.5	1.0	3.0	4.8	81.4	4.22	8.2	Frozen	6.9
January 21-25	5	−19.1	67.9	9.0	7	70.5	35.6	2.3	3.9	5.9	78.1	4.44	12.6	3.61	2.4
January 26-30	6	−17.8	66.6	9.2	8	71.3	36.8	4.1	6.4	10.7	71.3	4.60	12.7	6.45	5.7
January 31-February 4	7	−16.7	65.5	9.4	8	73.0	38.0	6.4	7.7	11.4	77.7	5.84	21.4	8.35	9.8
February 5-9	8	−15.1	63.9	9.7	7	74.2	39.3	2.7	5.5	8.5	71.0	4.18	21.1	Frozen	11.2
February 10-14	9	−13.5	62.3	10.0	5	75.4	40.4	0.3	6.3	8.1	73.4	3.86	19.1	Frozen	26.2
February 15-19	10	−11.8	60.6	10.3	8	76.4	41.5	6.5	9.1	14.7	71.3	5.54	16.2	9.10	3.0
February 20-24	11	−10.0	58.8	10.6	8	77.5	42.6	+2.7	4.0	8.6	74.0	4.42	20.1	Frozen	9.9
February 25-March 1	12	− 8.2	57.0	10.8	7	78.5	43.8	−0.4	1.8	7.8	65.9	3.02	11.9	Frozen	3.2
March 2-6	13	− 6.2	55.0	11.2	3	79.3	45.1	−0.6	3.9	10.9	62.3	2.94	9.9	Frozen	0.0
March 7-11	14	− 4.3	53.1	11.4	9	80.2	47.0	7.1	10.9	17.1	71.9	5.94	22.3	3.05	12.2
March 12-16	15	− 2.3	51.1	11.8	7	81.0	49.7	3.8	7.1	15.2	59.9	3.94	15.7	Frozen	0.5
March 17-21	16	− 1.4	49.2	12.0	9	81.6	53.1	8.2	12.0	22.4	68.7	5.96	15.4	Frozen	12.0
March 22-26	17	+ 1.6	47.2	12.4	7	82.3	56.0	5.9	9.8	18.4	63.5	4.80	18.2	Frozen	2.7
March 27-31	18	+ 3.6	45.2	12.6	9	82.9	58.7	7.0	10.0	17.3	69.5	5.44	13.1	Frozen	0.9
April 1-5	19	+ 5.5	43.3	13.0	8	83.4	61.0	7.0	10.3	19.2	70.0	8.40	14.2	12.05	13.8
April 6-10	20	7.4	41.4	13.3	8	83.7	63.7	9.8	14.8	28.9	63.2	6.06	9.7	9.65	20.1
April 11-15	21	9.2	39.6	13.5	9	84.1	65.8	8.1	11.5	27.0	66.2	5.62	11.0	11.40	7.3
April 16-20	22	11.0	37.8	13.8	6	84.5	67.8	8.6	13.8	23.6	60.8	6.14	13.9	20.40	0.0
April 21-25	23	12.7	36.1	14.2	7	84.8	69.5	11.2	15.6	30.9	59.8	6.30	17.4	20.25	7.3
April 26-30	24	14.3	34.5	14.4	8	85.2	71.0	11.8	16.4	32.9	61.5	6.82	11.0	15.20	8.9
May 1-5	25	15.8	33.0	14.6	6	85.4	72.1	12.8	18.5	31.9	59.9	7.78	9.4	15.00	5.5
May 6-10	26	17.2	31.6	14.9	7	85.5	73.3	14.8	19.4	32.9	61.3	9.02	11.5	12.00	9.6

Data, by pentads, for Montsouris, 1889, as published by Descroix or specially computed—Continued.

Dove's pentad limits.	No.	Sun's location.		Sunshine.		Actinic degrees—maximum possible.		Shade temperature.		Sun temperature (daily maximum).	Relative humidity.	Vapor tension.	Hourly wind velocity.	Total daily evaporation.	Total rainfall.
		Dec'l.	Zen. distance.	Maximum duration.	Average cloudiness.	Noon.	Daily average.	Daily mean.	Daily maximum.						
1889.		°	°	*h.*	*Tenths.*			°	°	° *C.*	*P. ct.*	*mm.*			*mm.*
May 11-15	27	18.5	30.3	15.1	7	85.7	74.0	15.2	20.3	37.8	57.4	8.56	7.2	14.80	4.1
May 16-20	28	19.7	29.1	15.4	8	85.8	74.8	14.7	18.4	33.4	66.0	8.74	9.1	12.15	7.4
May 21-25	29	20.7	28.1	15.5	6	85.9	75.4	17.9	22.8	40.9	59.5	11.08	9.0	14.15	4.8
May 26-30	30	21.5	27.3	15.7	7	86.0	75.9	16.3	20.5	39.8	64.8	9.92	12.4	15.20	44.7
May 31-June 4	31	22.3	26.5	15.9	5	86.2	76.2	17.3	22.2	37.4	64.5	11.10	9.5	13.95	12.6
June 5-9	32	22.8	26.0	16.0	5	86.2	76.5	21.1	25.8	43.1	66.6	14.02	11.8	19.40	19.6
June 10-14	33	23.2	25.6	16.0	5	86.3	76.7	16.5	20.8	38.8	62.8	9.70	13.8	20.50	8.5
June 15-19	34	23.4	25.4	16.1	5	86.3	76.8	18.4	23.3	42.5	60.1	10.80	14.7	24.65	1.2
June 20-24	35	23.4	25.4	16.1	3	86.3	76.9	19.4	24.6	46.8	53.6	10.76	11.4	28.65	3.6
June 25-29	36	23.3	25.5	16.1	4	86.3	76.8	20.3	26.1	41.4	54.5	10.96	10.6	27.15	0.8
June 30-July 4	37	23.0	25.8	16.0	3	86.3	76.7	18.8	24.5	37.6	55.7	10.18	14.4	28.35	0.0
July 5-9	38	22.6	26.2	15.9	5	86.2	76.4	19.9	25.3	39.0	60.9	12.02	14.4	25.60	8.5
July 10-14	39	21.9	26.9	15.8	8	86.1	76.1	20.6	25.4	41.0	71.0	13.64	11.4	14.65	15.8
July 15-19	40	21.1	27.7	15.6	7	86.1	75.7	16.8	21.5	35.5	56.5	9.24	12.3	19.15	1.0
July 20-24	41	20.2	28.6	15.5	8	85.9	75.1	17.8	22.2	36.3	55.5	9.32	14.3	20.80	1.3
July 25-29	42	19.1	29.7	15.2	9	85.7	74.4	16.9	20.4	32.3	69.4	10.52	14.3	16.55	9.8
July 30-August 3	43	17.9	30.9	15.0	5	85.6	73.7	20.0	25.8	39.4	61.0	12.26	9.9	19.25	0.0
August 4-8	44	16.6	32.2	14.8	6	85.5	72.7	18.7	24.0	38.8	61.4	11.22	11.0	20.00	0.1
August 9-13	45	15.2	33.6	14.5	7	85.3	71.7	17.3	22.1	34.9	62.6	10.18	14.2	18.40	10.7
August 14-18	46	13.6	35.2	14.3	7	85.0	70.3	18.5	21.8	36.6	59.2	11.00	14.7	16.45	0.7
August 19-23	47	12.0	36.8	14.0	8	84.7	68.9	17.0	21.5	30.1	67.9	11.34	21.9	13.62	26.8
August 24-28	48	10.3	38.5	13.7	5	84.3	67.0	14.0	18.7	30.2	64.4	8.54	9.3	9.35	7.1
August 29-September 2	49	8.5	40.3	13.4	2	84.0	65.2	20.6	27.4	38.9	56.1	12.34	6.1	17.50	0.1
September 3-7	50	6.7	42.1	13.1	7	83.5	62.8	18.5	22.3	31.6	68.7	11.14	9.0	16.25	1.4
September 8-12	51	4.8	44.0	12.8	2	83.1	60.1	18.7	25.0	38.5	54.1	10.46	4.9	14.85	0.0
September 13-17	52	2.9	45.9	12.6	4	82.6	58.0	13.9	17.9	27.6	61.4	8.32	13.1	27.10	0.0

September 18-22	53	+ 0.9	47.9	12.3	6	82.0	55.2	11.7	16.1	26.6	62.4	7.14	10.7	14.50	9.8
September 23-27	54	− 1.0	49.8	12.0	4	81.4	51.9	11.4	16.6	27.3	59.9	6.76	10.4	13.85	0.8
September 28-October 2	55	− 3.0	51.8	11.7	9	80.7	48.5	11.4	15.4	21.6	70.8	7.50	9.1	9.10	12.6
October 3-7	56	− 4.9	53.7	11.4	7	80.0	46.3	10.9	15.3	23.5	72.8	7.96	14.7	6.85	4.8
October 8-12	57	− 6.8	55.6	11.1	7	79.2	44.4	11.1	14.4	22.4	72.9	7.64	17.5	8.45	28.5
October 13-17	58	− 8.7	57.5	10.8	5	78.2	43.2	10.3	15.2	24.3	71.2	8.08	11.3	7.00	1.6
October 18-22	59	−10.5	59.3	10.5	8	77.2	42.3	11.1	14.0	21.3	73.9	7.64	14.1	6.30	21.9
October 23-27	60	−12.3	61.1	10.2	7	76.1	41.2	9.6	12.8	16.8	75.7	7.28	14.3	6.50	7.3
October 28-November 1	61	−13.9	62.7	9.9	5	75.0	40.1	10.5	14.6	21.9	71.3	7.62	11.8	9.15	5.8
November 2-6	62	−15.5	64.3	9.6	7	74.0	38.8	9.3	12.4	15.8	74.6	6.88	13.4	7.28	14.6
November 7-11	63	−17.0	65.8	9.4	8	72.8	37.4	10.3	12.8	15.3	77.3	7.62	8.3	6.45	0.4
November 12-16	64	−18.3	67.1	9.1	2	71.6	36.2	7.3	12.9	15.9	75.7	6.54	6.9	4.85	0.0
November 17-21	65	−19.6	68.4	8.9	8	70.6	35.3	4.2	6.6	7.5	83.9	5.48	5.9	Frozen	0.3
November 22-26	66	−20.7	69.5	8.7	5	69.0	34.3	5.7	10.1	11.0	78.2	5.92	16.3	Frozen	6.4
November 27-December 1	67	−21.6	70.4	8.5	7	68.4	33.2	2.2	4.6	7.4	70.9	3.92	15.4	Frozen	6.9
December 2-6	68	−22.3	71.1	8.4	4	67.4	32.4	− 1.6	0.6	2.3	73.4	3.14	14.6	Frozen	6.0
December 7-11	69	−22.9	71.7	8.3	9	66.7	31.6	+ 1.0	2.8	4.3	81.4	4.06	12.3	Frozen	10.8
December 12-16	70	−23.3	72.1	8.2	7	66.2	31.2	0.2	2.7	3.3	83.0	3.92	8.7	Frozen	4.5
December 17-21	71	−23.4	72.2	8.2	10	65.9	30.9	1.0	2.7	2.2	90.9	4.24	13.4	Frozen	0.3
December 22-26	72	−23.4	72.2	8.2	8	66.0	31.0	7.1	9.6	10.4	84.7	6.52	18.6	Frozen	10.7
December 27-31	73	−23.2	72.0	8.2	8	66.2	34.3	− 0.4	1.6	1.9	80.3	3.60	10.2	Frozen	0.0
January 1-5	74	−22.7	71.5	8.3		66.7	34.7								

THE RESULTS OF RECENT STUDIES BY ANGOT.

In 1880 the Central Meteorological Bureau of France, under the minister of public instruction, organized a system of phenological observations; the resulting data have been studied by Angot in a series of memoirs.

In his first paper (1882) Angot grouped the dates of the wheat harvest as observed during 1880 and 1881 at several hundred stations in France in groups of four or five stations and plotted these upon maps showing the elevations of the stations. By a careful comparison of neighboring stations he shows that the date of the harvest is everywhere quite uniformly retarded with increase of elevation, and at the rate of four days in time for every hundred meters of ascent. Apparently this retardation is the general result of a complex system of influences in which rainfall, drainage, soil, sunshine, temperature, and other local peculiarities combine. It is evident that the special influence of any local climate on the crop can not be successfully studied until the observations have been corrected for the general influence of elevation. He therefore reduces all the dates of harvest to sea level by applying the preceding correction.

A similar calculation showed him that the phenomena of flowering are also retarded at precisely the same rate of four days per 100 meters of elevation and these dates also are thus reducible to sea level.

Angot's charts, showing the dates of flowering and harvesting thus reduced to sea level, show great regularity and the isanthesic lines show the perfect regularity with which the reduced epoch of flowering begins in southern France on the 11th of May and advances northward until it reaches the northern boundary of France on the 25th of June; in a similar way the harvesting of winter wheat begins in southern France on the 10th of June (reduced epoch) and in northern France on the 9th of August. The variations of these isanthesic lines from year to year may be compared with the ordinary charts of temperature reduced to sea level or with other meteorological data in a very simple manner.

Angot has modified and apparently improved the methods of determining the influence of temperature on the date of flowering and harvesting. He says that since 1837 Boussingault's idea that the ripening demands a certain sum total of heat, which is constant for each species of plant, has been generally adopted. At first this sum total was calculated by adding together all mean daily temperatures from the germination of the seed or the beginning of vegetation after rejecting such means as were below freezing point. Then, as C. H. Martins, De Gasparin, and A. de Candolle had shown

that the temperatures useful to the plant vary with the species and are decidedly above freezing, therefore students have taken other limits. Thus Gasparin and Hervé Mangon adopt 6° C. for the initial temperature in the growth of wheat. In order to ascertain the proper method of counting temperatures Angot has accomplished the labor of prosecuting three parallel computations by three different methods, as follows:

(A) *First method.*—By observations of daily maximum and minimum temperatures. In this method Angot has examined separately the observed maxima and minima of the thermometer in the shade. After rejecting all observations below 6° C., he subtracts 6° C. from all the others and takes the separate sums of the remaining maxima and minima for each month and then the average of these two sums, which consequently represents a sum total of heat received during the month in excess of 6° C.

(B) *Second method.*—By the daily means. In this method the mean of each day is first computed by taking the average of the maximum and minimum; 6° C. is then subtracted from each of these daily means and all negative remainders are rejected. The sum of the positive remainders represents the sum total of heat received in excess of 6° C.

(C) *Third method.*—By maximum temperatures alone. In this method, which is a modification of that proposed by Hoffmann, a maximum thermometer is exposed to the direct rays of the sun and the sum total of the maximum temperatures is used by Hoffmann. But Angot prefers to use the maximum thermometer in the shade, as in the first method, and, as before, takes the sum total of all the positive remainders after subtracting 6° C.

In all these methods the principal difficulty is to fix the epoch from which the summation should begin. Sometimes the date of sowing has been adopted as this epoch, but from the date of sowing up to the date of sprouting the seed and the young plant are subjected only to the temperature of the soil, and not to that of the air, which often differ considerably. It would perhaps be better to start with the date at which the plant appears above the earth, but the date of sprouting is not generally given by observers. He therefore provisionally adopts the 1st of December as the point of departure and calculates the sum total of temperatures for the nine stations in France for which the dates of flowering and harvesting of winter wheat have been best determined for the years 1880 and 1881. The agreement among themselves of the numbers calculated by these three methods for nine stations and two different years is such that no decision can be arrived at as to which method is the best, and such decision is reserved for a future study of other harvests.

A similar elaborate study of the harvest of rye gave the following results:

(1) Retardation for altitude is approximately four days per 100 meters, with some indication that the correct figure is rather less than this.

(2) The date of harvest reduced to sea level begins with the 5th of June in southern France and ends with the 25th of July on the northern border.

(3) The sum total of temperatures computed by the three methods A, B, C, above mentioned, shows that whatever method be finally adopted as the best, these sums are less for rye than for winter wheat.

A similar study for spring barley shows the following results:

(1) A retardation of four days per 100 meters of altitude sufficiently harmonizes the observations.

(2) A retardation of thirty or forty days in the date of sowing has no appreciable effect on the date of harvest, which varies from the 20th of June in southern France to the 14th of August on the northern boundary.

(3) The sum total of temperatures from sowing to harvest is too variable to be determined.

A similar study of the flowering of the narcissus (*Narcissus pseudonarcissus*) shows that the retardation of the date of flowering is at the rate of four to five days per 100 meters, and four days can be adopted without notable error.

A study of the currant (*Ribes rubrum*) shows that the retardation is between three and four days per 100 meters. The sum total of heat from December 1 up to the date of flowering, as deduced by the second and third methods, but under three different assumptions—i. e., that the initial temperature is 4°, 6°, 8°, respectively, seems to show that 4 is the proper figure for this plant.

A study of the flowering of the lilac shows that a retardation of four days per 100 meters best satisfies the observations of both leafing and flowering. The latter begins in southern France on the 22d of March and ends in northern and eastern France on the 6th of May. The calculation of the heat required for leafing shows that the most accordant results are obtained when we take the sum of maximum daily temperatures above 4° C. and count from the date of the last heavy frost, which sum is about 360° C. For the flowering, on the contrary, we have to take the sums of the mean daily temperatures, counting from 4° C. and from the same date of frost, which sum is then 350° C., while the sum of the maximum daily temperatures would have given 695° C.

A study of the leafing and flowering of the horse-chestnut (*Æsculus hippocastanum*) shows that the retardation of four days per 100 meters also satisfies these observations. The dates of leafing, as

reduced to sea level, begin with March 12 in southern France and extend to April 21 in northern France. The dates of flowering begin with April 6 in southern France and extend to May 16 in northern France.

The sums of temperatures are counted from the last severe frost, and the most accordant results are obtained when the sums of daily maxima are taken, counting from 2° C. The sum total is 715° to date of leafing, and from leafing to flowering 1,070°.

The leafing of the birch is found by Angot to have the same rate of retardation—very little less than four days per 100 meters—and the reduced epochs of leafing begin the 9th of March at the southeast corner of France and extend to the 16th of April at the northern border. The sums of temperatures up to the time of leafing are best computed by taking the sums of daily maxima above 2° C., but are very uncertain.

The leafing of the common oak (*Quercus pedunculata*) has a retardation of four days per ascent of 100 meters, and the reduced epochs begin with the 6th of April in southern France and end with the 6th of May in northern France. We can provisionally admit that the leafing of the oak occurs when the sum of the maximum daily temperatures has attained 940° C., counting above 2° C. and from the date of the last heavy frost.

The flowering of the elder (*Sambucus nigra*) has an approximate retardation of four days per 100 meters. The reduced dates begin on the 6th of April in southern France and end on the 10th of June in northern France. The flowering of the elder occurs when the sum of the mean daily temperatures since the date of the last frost has attained 840° C. if we count from 2°, or 630° if we count from 4° C.

The flowering of the common linden (*Tilia europæa*) or the *Tilia silvestris* is retarded three days per 100 meters' ascent for the mountainous countries, but four days is adopted for the whole of France, and the reduced dates of flowering begin with the 1st of May in southeastern France and extend to the 20th of June in northern France. The flowering of the linden occurs when the sum of the mean daily temperatures, counting from the last heavy frost and above 2° C., has attained 1,090° C.

It would seem to result from all this that the leafing of the trees and shrubs occurs when the sum total of the maximum daily temperatures, counting above a certain limiting value and from the date of the last heavy frost, has attained a certain value characteristic of each plant. But for a certain number of plants the flowering seems rather to depend on the sum of the mean daily temperatures.

In his second memoir Angot (1886) studied the additional data for the years 1882 and 1883. A new determination of the influence of altitude on the epoch of leafing again gave an average retardation of four days for each 100 meters of altitude for the lilac, the chestnut, the birch, and the oak. The average mean daily temperature of the air at the date of leafing varies between 5° and 12° C. for the lilac, with an average of 9.1°; from 4° to 14° C., with an average of 10.1°, for the chestnut; from 7° to 15° C., with an average of 10.7°, for the birch; from 5° to 16°, with an average of 11.3°, for the oak. These ranges are so large that it is impossible to indicate any simple relation between the leafing of these plants and the mean daily temperature at this epoch. The mean of the daily maxima were also computed for the epoch of leafing, and were 14.6° for the lilac, 15.7° for the chestnut, 16.1° for the birch, and 16.4° for the oak. But again the variations were too large to attach any phenological importance to these numbers.

As to the sum total of temperatures Angot adopts, not a constant date, as December 1 or January 1, but dates that are variable for each station and each year and approximately represent the close of the last period of freezing weather. They vary in this case between the 18th of January and the 13th of February. After laborious calculations by different methods and starting from different initial temperatures he concludes that the leafing of the four plants under consideration occurs when the sum of the mean daily temperatures, counted from 0° C., or the sums of the maximum daily temperatures, counting from 0° C. and beginning at the date of the commencement of vegetable growth as above defined, attains the values given in the following table:

Plant.	Sums of daily means.	Sums of daily maxima.
	° C.	° C.
Lilac	333	550
Indian chestnut	522	845
Birch	517	838
Oak	677	1,082

In order to decide which of these two modes of calculation, daily mean or daily maxima, are most proper it will be necessary to operate upon a much longer series of observations.

The flowering of the narcissus, the lilac, the chestnut, the elder, and the linden was studied in a manner similar to that of the leafing. The retardation for altitude is, as before, four days to the 100 meters. The man daily temperature at the date of flowering is: For the narcissus, 6° to 14° C., average 9.4°; for the lilac, from 8° to 15° C.,

average 12.2°; for the chestnut, 8° to 16° C., average 12.0°; for the elder, 9° to 20° C., average 13.9°; for the linden, 12° to 21° C., average 16.4°. The mean daily maximum temperatures at the date of flowering for these same plants is as follows:

Plant.	Daily maxima.		Daily mean.	
	Range.	Mean.	Range.	Mean.
	° C.	° C.	° C.	° C.
Narcissus	9..20	14.9	6..14	9.4
Lilac	13..21	16.6	8..15	11.2
Chestnut	13..25	17.6	8..16	12.0
Elder	14..26	19.7	9..20	13.9
Linden	17..29	22.5	12..21	16.4

Evidently the maximum temperatures have no clearer connection with the date of flowering than have the mean daily temperatures.

The sums of temperatures from the beginning of vegetation to the date of flowering have also been computed by different methods and from different initial temperatures. The following are the results when the initial temperature is 0° C.:

Plant.	Sums of positive daily means.	Sums of positive daily maxima.
	° C.	° C.
Narcissus	359	591
Lilac	613	983
Chestnut	771	1,217
Elder	990	1,542
Linden	1,277	1,938

Here, again, as in previous cases, the relative value of the different methods of taking account of the temperature is determined numerically by taking the sums of the departures from the average for the individual stations and years. In the present case the mean departures as thus determined are exactly the same for both methods, so that four years of observations, 1880–1883, have not sufficed to decide as to which mode of calculation it is proper to adopt as the best. A similar calculation as to the amount of heat received by the lilac and the chestnut between the epochs of leafing and flowering leads to the same indecision as to the methods of calculation. The actual sums between the leafing and the flowering are as follows:

Plant.	Sums of positive daily means.	Sums of positive daily maxima.
	° C.	° C.
Lilac	280	433
Chestnut	250	372

The flowering and ripening of winter wheat during 1882 and 1883 has been studied on the basis of data from about 500 stations, combined with the previous data for 1880 and 1881.

The mean daily temperature at the time of flowering is for rye 13.3°; but the individual numbers range from 9° to 18°; similarly for winter wheat the mean is 16.2° and the range from 10° to 21°. The commencement of vegetation for winter wheat is uniformly adopted as December 1. The sums of the mean daily temperatures have been calculated from several points of departure and seem to prove that the lower limit of useful temperatures is very nearly 5° C., so that we can take 6° C. as the point of departure, as has been done by many authors.

The sums of the mean daily temperatures, less 6° C., rejecting the negative remainders and counting from the 1st of December, are as follows:

Periods for winter grain.	Rye.	Wheat.
	° *C.*	° *C.*
From December 1 to flowering	420	596
From December 1 to harvest	955	1,099
From flowering to harvest	535	503

The harvest date for spring barley is shown to depend in 1882 and 1883 quite as little on the date of sowing as it did in 1881.

The retardation due to altitude is as before, four days per 100 meters. Adopting the 20th of March as an average date of sowing, the sums of the mean daily temperatures have been considered up to the date of harvest, with different assumptions as to the fundamental temperature. As before, the best result is given when the sums are taken of the excess of the mean daily temperatures above 6° C., and the resulting figure, 984, is seen to be between the two figures for rye and winter wheat.

In his third memoir Angot (1888) studies the phenomena of 1884 and 1885 in combination with the preceding. The same allowance is made for rates of retardation. The relation between the times of leafing, the mean daily temperature at that date, and the maximum

temperature at that date, is computed by the same process as before, with the following results for the years 1884 and 1885:

Plant.	Daily mean temperature.		Daily maximum temperature.	
	Mean.	Range.	Mean.	Range.
	° C.	° C.	° C.	° C.
Lilac	9.1	5.7..14.2	14.7	4.7..20.8
Indian chestnut	9.6	6.3..13.7	15.3	10.9..22.3
Birch	10.1	5.8..14.3	15.9	9.7..22.7
Oak	10.3	6.0..15.1	15.7	11.9..21.0

The mean values here given agree well with those of the previous years, but the individual numbers have such a wide range that we can not conclude any simple relation between the leafing and the mean temperatures.

The relation between the leafing and the sums of temperatures is found, as before, by assuming the end of the last period of frost as the commencement of vegetation; for these years this corresponds with the last few days of January. The useful temperatures are considered to be those above 0° C., and Angot has computed both the sums of the mean daily temperatures and also the sums of the maxima alone with the following results:

Plant.	Sums of daily means.		Sums of daily maxima.	
	1884.	1885.	1884.	1885.
	° C.	° C.	° C.	° C.
Lilac	428	414	686	666
Chestnut	568	575	924	925
Birch	609	587	968	944
Oak	709	717	1,149	1,146

The reliability of these sums is, as before, determined by examining the departures, although not according to the strict rules of the law of probabilities of errors, but sufficiently so to show that the uncertainties of each of these figures is larger than the differences for successive years. The average of the two years, 1884 and 1885, are considerably higher than those for the previous four years.

The flowering of the lilac, chestnut, elder, and linden is again investigated by using the observations at some 1,200 stations or less. The reduction for altitude is as before. The mean daily temperatures

and the maximum daily temperatures for the dates of flowering give the results in the following table:

Plant.	Daily mean temperature.		Daily maximum temperature.	
	Mean.	Range.	Mean.	Range.
	° C.	° C.	° C.	° C.
Lilac	10.1	4.7..15.4	15.6	9.1..22.0
Chestnut	11.7	6.7..17.1	17.9	13.5..26.3
Elder	15.3	10.7..19.6	22.2	15.0..29.5
Linden	16.3	12.9..20.8	23.0	16.9..29.9

Again the accord with the results of previous years is satisfactory, but the individual variations are so large as to show that there is no clear connection between the epochs of flowering and the mean temperatures. Next the sums of temperatures received by these plants since the last severe cold is computed, assuming 0° C. as the initial temperature, with the following results:

Plant.	Sums of daily mean temperatures.		Sums of daily maximum temperatures.	
	1884.	1885.	1884.	1885.
	°C.	°C.	°C.	°C.
Lilac	689	672	1,097	1,070
Chestnut	846	841	1,345	1,304
Elder	1,033	1,108	1,619	1,685
Linden	1,366	1,354	2,091	2,022

These sums agree well among themselves for the two years, but are notably higher than the sums for the four previous years, the excess being so much larger than the uncertainty, as deduced from the agreement of the numbers among themselves, that we can scarcely consider that such sums as these represent the true influence of climate on these plants.

The dates of flowering and harvest of rye and winter wheat at 700 or 800 stations give the following results:

The mean temperatures at the date of flowering are, for rye, in 1884, 14° C., and 1885, 12.2° C.; for winter wheat, in 1884, 15.1° C., in 1885, 16.4° C. These figures agree well with the previous four years, but the individual discrepancies show that there is no simple relation between the flowering of these plants and the mean temperature.

Again, the sums of temperatures are computed from the 1st of December; 5° C. is subtracted from all the mean daily temperatures and the sums of the positive remainders are given. Since in previous years 6° C. has been adopted, whereas the evidence points toward a lower figure, therefore Angot now gives the results of a recomputa-

tion of the five years, adopting 5° C. as the lower limit of useful temperatures, with the following results:

Sums of mean daily temperatures, less 5° C. and rejecting negative remainders, from December 1 up to the dates of flowering and of harvesting.

Year.	Rye.		Winter wheat.	
	Flowering.	Harvesting.	Flowering.	Harvesting.
1880	537	1,113	730	1,235
1881	602	1,180	793	1,311
1882	496	1,075	720	1,271
1883	460	1,076	638	1,248
1884	527	1,089	727	1,268
1885	469	1,047	686	1,245
Mean	515	1,096	716	1,263

The differences between the numbers for flowering and harvesting show, as in previous years, that although winter wheat requires more heat (716° C.) to bring it up to the flowering point than does rye (515° C.), yet after having attained that point the wheat requires less heat (547° C.) than does the rye (581° C.) in order to ripen the grain to the harvest. This fact, which has shown itself in each of the six years, can be considered as well established.

The harvest of spring barley.—The dates of harvest are, as before, reduced to sea level by allowing for retardation at the rate of four days per 100 meters. The sums of mean daily temperatures, less 5° C., counting from the 21st of March, which is the mean date of sowing, and up to the date of harvest, are given for each year in the following table:

Year.	Spring barley harvest—sums of temperatures.	Year.	Spring barley harvest—sums of temperatures.
	° *C.*		° *C.*
1880	1,071	1883	1,083
1881	1,110	1884	1,049
1882	1,128	1885	1,042

The general mean for these six years is (within the range of its probable error) the same as the corresponding figures for winter rye.

In a fourth memoir, Angot (1890) gives similar computations for the harvests of 1886 and 1887 in France, the number of stations being now appreciably larger than in the preceding years. A new computation of the retardation due to altitude gives him 3.7 days per 100 meters for the lilac, 4.0 for the chestnut, 3.7 for the elder,

and 3.5 for the oak. For all these he adopts 4 days, as in previous years.

Leafing.—The mean temperatures at the dates of leafing for 1886 and 1887 are given, as follows:

Data for 1886 and 1887.

Plant.	Mean of daily temperature.	Mean of daily maximum temperature.	Plant.	Mean of daily temperature.	Mean of daily maximum temperature.
	° C.	° C.		° C.	° C.
Lilac	9.4	14.8	Birch	9.9	15.3
Chestnut	10.6	16.2	Oak	11.7	17.6

The sums of temperatures received by these plants from the last freezing period up to the time of leafing, and counting from 0° C. as the initial temperature, are as follows:

Plant.	Sums of daily means.		Sums of daily maxima.	
	1886.	1887.	1886.	1887.
	° C.	° C.	° C.	° C.
Lilac	356	402	622	772
Chestnut	469	531	788	983
Birch	465	531	796	981
Oak	622	682	1,016	1,208

The flowering of the lilac, chestnut, elder, and linden.—A new determination of the rate of retardation of flowering for these plants gives 4.7, 4.2, 4.4, and 3.8 days per 100 meters, respectively, for which, as before, 4 days is adopted. The mean temperatures at the times of flowering for the years 1886 and 1887 are as follows:

Plant.	Daily means.	Daily maxima.
	° C.	° C.
Lilac	12.2	17.8
Chestnut	12.8	18.7
Elder	15.2	21.0
Linden	16.4	22.5

The sums of temperatures above 6° C., counting from the last freezing period and up to the date of flowering, for the years 1886 and 1887 are as follows:

Plant.	Sums of daily means.		Sums of daily maxima.	
	1886.	1887.	1886.	1887.
	° C.	° C.	° C.	° C.
Lilac	621	661	1,020	1,184
Chestnut	704	773	1,147	1,351
Elder	975	1,001	1,543	1,682
Linden	1,269	1,245	1,949	2,014

The probable errors of these sums, considered individually, are quite large, and their agreement from year to year is not sufficient to justify the belief that we have attained to a satisfactory expression for the connection between the temperature and the date of flowering.

Flowering of rye and winter wheat—Harvest of rye, winter wheat, and spring barley.—A new investigation, based on an increased number of stations for the years 1886 and 1887, gives for the rate of retardation of these epochs the following figures: Flowering of rye, 4.2 days per 100 meters; flowering of winter wheat, 4; harvest of rye, 4.5; harvest of winter wheat, 4.3; harvest of spring barley, 4.2. We can, therefore, as before, take 4 days as an approximate value for all these phenomena.

The mean temperature at the time of flowering is determined, both for daily means and for daily maxima, as follows:

Flowering of plant.	Daily mean.		Daily maxima.	
	1886.	1887.	1886.	1887.
	° C.	° C.	° C.	° C.
Rye	15.4	12.3	22.1	18.3
Wheat	16.2	17.3	22.0	24.3

Again; the average numbers agree well from year to year, but the individuals from which they are derived have a wide range.

The sums of the mean daily temperatures, less 5° C., counting from December 1 for the winter rye and wheat, but from March 21, for the spring barley, are as follows:

Sums of temperature.

Plant and stage.	1886.	1887.	Average.
	° C.	° C.	° C.
Flowering of rye	313	415	364
Flowering of winter wheat	735	630	682
Harvest of rye	1,080	1,017	1,048
Harvest of winter wheat	1,286	1,185	1,236
Harvest of spring barley	1,214	1,120	1,167

From the flowering to the harvest, on the average of these two years, rye has received 1,048—364=684° C., and winter wheat 1,236—682=554° C., but on the average of eight years, 1880–1887, the sums of temepratures, less 5° C., have been, for rye, from December 1 to the flowering, 477° C., and from flowering to harvest, 607° C.; for winter wheat the numbers are, respectively, 708° to 549° C. From the beginning of vegetation up to harvest the numbers are: For rye, 1,084° C.; winter wheat, 1,256° C.; spring barley, 1,103° C. These results can be considered as having definitely established the fact that

in France rye requires less heat to bring it to the harvest and winter wheat more; but, on the other hand, from the flowering to the harvest rye requires more and winter wheat less.

The following table gives a résumé of Angot's general average dates and temperatures for sea level for the whole of France for the years 1880–1887:

Plant.	Mean daily temperature when—	
	Leafing occurs.	Flowering occurs.
	° C.	° C.
Lilac	9.1	11.2
Indian chestnut	10.1	14.6
Birch	10.4	
Oak	11.1	
Elder		17.1
Linden		18.9
Rye		13.4
Winter wheat		16.2

As to the sums of the mean daily temperatures above 5° C., counting from December 1:

Plant.	Sums of temperature at time of—	
	Flowering.	Harvest.
	° C.	° C.
Rye	477	1,085
Winter wheat	707	1,256

The harvest of spring barley occurs when the sum of the mean daily temperatures, less 5° C. and counting from March 21 or the average date of sowing, amounts to 1,102° C.

The large variations of the individual numbers whose means are given above are probably due to special meteorological conditions, and Angot states that he will report upon these if it is possible to take them into account when ten whole years of observations have accumulated.

REQUESTS FOR PHENOLOGICAL OBSERVATIONS.

The influence of a climate upon cultivated crops is parallel to its influence upon uncultivated plants, and the comparative study of climates in their relations to plants can be attained by careful observations of the general features of the natural life of special plants that are widely distributed over the earth. To this end several special invitations have been issued urging the observation of certain phenological stages.

(A) Hoffmann and Ihne have published a special list of plants selected by them as a result of many years' experience in Europe. The following calendar, copied from the appeal for "phenological observations," contained in their "Beitrage, 1884," shows the names of the plants and the approximate date in Europe of the phenomena that they wish to have observed. Corresponding observations in America are desirable and should be communicated either to them directly or to the journals of botany, climatology, or general science, or to the botanist of the Department of Agriculture.

CALENDAR FOR PHENOLOGICAL OBSERVATIONS.

Instructions.—Plants should be examined daily. The object is to obtain for individual stations average data characteristic of the climate; therefore plants that are known to be exceptionally early or late, and those that are forced by special treatment, or those that are artificially trained on walls are not to be considered. It is not necessary to confine the observations to the same plant year after year, but to those individuals that represent the average conditions of the plant in nature.

For brevity the following notation may be used:

(P) Pollen disseminated (*Pollen effunditur.* Linne).

(1) Leaf, or the first visible surfaces of the leaves, or beginning of the leafing out or of the foliage (*frondescentia: prima folia explicantur* Linne; *erste Blattoberfläche* Hoffmann; *feuillaison* Quetelet).

(F) Full foliage: All leaves have appeared (*folatio perf.* Linne; *allgemeine Blatt* Hoffmann).

(2) Flower, or the first opening of the flower buds (*efflorescentia: primi flores ostenduntur* Linne; *erste Blüthe offen* Hoffmann; *floraison* Quetelet).

(3) Ripe fruit (*Prima fructus matura; baccœ definite coloratœ* Linne; *erste Frucht reif* Hoffmann; *maturation des fruits* Quetelet).

(H) Harvest, or first date of cutting cereals (*Ernte Anfang* Hoffmann; *Messis initium* Linne).

(4) Leaves color or fall (*foliorum pars major decolorata* Linne); *allgemeine Laubverfarbung* Hoffmann; *vollständige Entlaubung* Karl Fritsch; *Effeuillaison, chute des feuilles* Quetelet).

Phenological calendar for Giessen.

[Lat. 50° 35′ N.; long. 8° 12′ east of Greenwich; altitude, 160 meters.]

Date.	Plant.	Phase of vegetation.	Date.	Plant.	Phase of vegetation.
Feb. 10	Corylus avellana	Pollen.	May 28	Atropa belladonna	Flower.
Apr. 10	Æsculus hippocast.	Leaf.	June 1	Symphoricarpos racemosa.	Do.
13	Ribes rubrum	Flower.	2	Rubus idæus	Do.
17	Ribes aureum	Do.	2	Salva officinalis	Do.
17	Betula alba	Pollen.	5	Cornus sanguinea	Do.
18	Prunus avium	Flower.	14	Vitis vinifera	Do.
19	Prunus spinosa	Do.	20	Ribes rubrum	Fruit.
19	Betula alba	Leaf.	21	Ligustrum vulgare	Flower.
22	Prunus cerasus	Flower.	22	Tilia grandifolia	Do.
23	Prunus padus	Do.	26	Lonicera tatarica	Fruit.
23	Pyrus communis	Do.	30	Lilium candidum	Flower.
25	Fagus sylvatica	Leaf.	July 4	Rubus idæus	Fruit.
28	Pyrus malus	Flower.	5	Ribes aureum	Do.
May 1	Quercus pedunculata	Leaf.	19	Secale cereale hibern.	Harvest.
3	Lonicera tatarica	Flower.	30	Sorbus aucuparia	Fruit.
4	Syringa vulgaris	Do.	30	Symphoricarpos racemosa.	Do.
4	Fagus silv.	Full foliage.	Aug. 1	Atropa belladonna	Do.
4	Narcissus poeticus	Flower.	11	Sambucus nigra	Do.
7	Æsculus hippocast.	Do.	24	Cornus sanguinea	Do.
9	Cratagus oxyacantha	Do.	Sept. 9	Ligustrum vulgare	Do.
12	Spartium scoparium	Do.	16	Æsculus hippocast.	Do.
14	Quercus pedunculata	Foliage.	Oct. 10	do	Fall.
14	Cytisus laburnum	Flower.	13	Betula alba	Do.
16	Cydonia vulgaris	Do.	15	Fagus sylvatica	Do.
16	Sorbus aucuparia	Do.	20	Quercus pedunculata	Do.
28	Sambucus nigra	Do.			
28	Secale cereale hibern.	Do.			

(B) *Smithsonian list.*—In the United States calls for phenological observations were issued by the New York Agricultural Society in 1807 and by the Regents of the University of New York about 1820, also by Josiah Meigs as Commissioner of the General Land Office in 1817, but the principal work has been that undertaken by Prof. Joseph Henry, who as Secretary of the Smithsonian Institution established in 1848 a system of phenological observations undoubtedly arranged by Dr. Asa Gray or Dr. Arnold Guyot, and subsequently published a revised list of plants and epochs.

This system was also promulgated by the Department of the Interior on behalf of the Patent Office and its Bureau of Agriculture requesting accurate observations. The following is an abstract of Doctor Gray's schedule, which is here produced, because we shall have occasion to quote observations made on this plan, which was a slight modification of Quetelet's plan.

The observations thus collected by the Smithsonian, 1854–1859, were used by Fritsch in his memoir and list quoted on page 191.

The following observations were requested by the Smithsonian Institution:

(1) **Frondescence, or leafing:** When the buds first open and exhibit the green leaf.

(2) Flowering: When the anther is first exhibited—(*a*) in the most favorable location; (*b*) general flowering of the species.

(3) Fructification: When the pericarp splits spontaneously in dehiscent fruits or the indehiscent fruit is fully ripe.

(4) Fall or leaf: When the leaves have nearly all fallen.

List of plants recommended for observation by the Smithsonian Institution.

Pages of Gray's Manual of Botany.		Genera.	Common names.
Edition VI.	Edition V.		
118	119	Acer rubrum L	Red or soft maple.
117	119	Acer dasycarpum Ehrh	White or silver maple.
117	119	Acer saccharinum L	Sugar maple.
289	265	Achillea millefolium L	Millefoil or yarrow.
48	47	Actea rubra Willd	Red baneberry.
48	47	Actea alba Bigelow	White baneberry; necklace weed.
116	118	Aesculus hippocastanum L	Horse-chestnut.
116	118	Aesculus glabra Willd	Ohio buckeye.
116	118	Aesculus flava Ait	Yellow buckeye.
107	110	Ailantus glandulosa	Tree of heaven; ailanthus.
166	162	Amelanchier canadensis	Shad bush; service berry.
132	130	Amorpha fruticosa L	False indigo.
		Amygdalus nana L [a]	Flowering almond.
38	38	Anemone nemorosa L	Wind flower; wood anemone.
46	45	Aquilegia canadensis L	Wild columbine.
315	292	Arctostaphylos uva-ursa (Spreng)	Bearberry.
341	395	Asclepias cornuti Decaisne	Milkweed.
50	50	Asimina triloba Dunal	Papaw.
320	299	Azalea nudiflora L	Common red honeysuckle.
398	321	Bignonia (Tecoma) radicans (Juss)	Trumpet creeper.
479	455	Castanea vesca L	Chestnut.
468	448	Carya alba	Shagbark or shellbark hickory.
147	144	Cercis canadensis L	Redbud; Judas tree.
152	148	Cerasus virginiana D. C	Chokeberry or chokecherry.
152	149	Cerasus serotina D. C	Wild black cherry.
337	401	Chionanthus virginica L	Fringe tree.
47	48	Cimicifuga racemosa Ell	Black-snake root; rattlesnake root.
91	98	Claytonia virginica L	Spring beauty.
322	297	Clethra alnifolia	White alder or sweet pepper bush.
214	200	Cornus florida L	Flowering dogwood. (The real flower, not the white involucre.)
166	160	Cratægus crus-galli L	Cockspur thorn.
165	160	Cratægus coccinea L	Scarlet-fruited thorn.
165	159	Cratægus oxycantha L	English hawthorn.
315	293	Epigæa repens L	Trailing arbutus; ground laurel.
188	177	Epilobium angustifolium L	Willow herb.
528	533	Erythronium americanum Smith	Dogtooth violet or adder's-tongue.
335	401	Fraxinus americana L	White ash.
311	289	Gaylussacia resinosa Torrey and Gray	Black huckleberry.
389	335	Gerardia flava L	Yellow false foxglove.
103	107	Geranium maculatum L	Crane's bill.

[a] This genus of Rosaceæ is not in Gray's Manual of Plants Indigenous to United States.

List of plants recommended for observation by the Smithsonian Institution—Con.

Pages of Gray's Manual of Botany.		Genera.	Common names.
Edition VI.	Edition V.		
334	310	Halesia tetraptera Willd	Snowdrop tree.
38	38	Hepatica triloba Chaix	Round-lobed liverwort.
223	213	Houstonia cærulea Hook	Bluets; innocence, etc.
94	85	Hypericum perforatum L	St. John's wort.
513	516	Iris versicolor L	Large blue flag.
319	298	Kalmia latifolia L	Mountain laurel.
447	423	Laurus benzoin L (Benzoin odoriferum Nees.)	Spice bush; Benjamin bush.
289	265	Leucanthemum vulgare Lam	Ox-eye daisy; white weed.
219	202	Linnæa borealis (Gronov) (Linnæus)	Twin flower.
305	283	Lobelia cardinalis L	Red cardinal flower.
220	203	Lonicera tartarica L	Foreign spurs.
128	126	Lupinus perennis L	Wild lupine.
50	50	Liriodendron tulipifera L	Tulip tree; American poplar.
49	49	Magnolia glauca L	Small or laurel magnolia; sweet bay.
225	211	Mitchella repens L	Partridge berry.
464	444	Morus rubra L	Red mulberry.
55	56	Nymphæa odorata Ait	Sweet-scented water lily.
		Persica vulgaris L.[a]	Peach.
53	54	Podophyllum peltatum L	Mandrake; May apple.
536	545	Pontederia cordata L	Pickerel weed.
505	507	Pogonia ophioglossoides Nutt	Adder's-tongue.
164	161	Pyrus communis L	Common pear tree.
164	161	Pyrus malus L	Common apple tree.
475	450	Quercus alba L	White oak.
321	300	Rhododendron maximum L	Great laurel.
176	165	Ribes rubrum L	Red currant.
134	131	Robinia pseud-acacia L	Common locust.
134	131	Robinia viscosa Vent	Clammy locust.
155	157	Rubus villosus Ait	Blackberry.
217	205	Sambucus canadensis L	Common elder.
217	205	Sambucus nigra L	Black elder.
58	60	Sanguinaria canadensis L	Bloodroot.
57	58	Sarracenia purpurea L	Side-saddle flower.
170	168	Saxifraga virginiensis Michx	Early saxifrage.
526	530	Smilacina bifolia Ker. (Maianthemum canadense Gray.)	Two-leaved Solomon-seal.
174	166	Syringa vulgaris L. (Philadelphus coronarius Gray.)	Lilac.
303	280	Taraxacum dens-leonis Desf	Dandelion.
101	103	Tilia americana L	Bass wood; American lime or linden.
462	442	Ulmus americana L	American elm.
219	206	Viburnum lentago L	Sweet viburnum.

[a] This genus of the order Rosaceæ is not in Gray's Manual of Plants Indigenous to the United States.

Chapter XI.

ACCLIMATIZATION AND HEREDITY.

Scientific literature is full of illustrations of the natural and artificial acclimatization of plants and the influence of the annual variations of climate on the crops, all of which exemplify Linsser's general laws.

GRAPEVINE.

The following remarks and data relative to the changes of climate during the historical period, as given by Fritz (1889, pp. 266–269), will be valuable for further study and are referred to in another part of this work:

The northern boundary of vine culture in Europe extends from somewhat north of the mouth of the Loire, where the Marne empties into the Seine, to the junction of the Aar and the Rhine, north of the Erzgebirge, to about the fifty-second degree of latitude, descends along the Carpathians to the forty-ninth degree, extends on this parallel eastward, and near the Volga turns southward to its mouth, on the Caspian Sea. In the middle ages wine was made in the south of England, in Gloucester and Windsor; in the Netherlands; in Namur, Liege, Louvain; in northern Germany, in the Eifel range of hills in Sauerland (a division of Rhenish Prussia), on the slopes of the Ruhr Mountains, on the Weser as far as Raddesdorf, in lesser Waldeck (or Pyrmont); in Hesse as far as Fritzlar; in Thuringia, in Brandenburg, and in lower Lusatia; in Berlin, Brandenburg, Oderberg, Guben; in Prussia, at Kulm, Neuenburg, Thorn, Marienburg, even beyond Königsberg; in Kurland (Courland), and even in Seeland (Zealand) the vine has been cultivated in great quantities. Although we have very favorable accounts of many harvests in those times, even for the highest of the latitudes mentioned above, still one must not generalize too far. The sensation of taste is very variable and often peculiar. We frequently at the present time obtain a very sour beverage from countries reputed to produce good wine, and in the north we eat grapes which farther south are considered very sour. It must be taken for granted that in those times when there was no communication over long distances they were not very exacting in regard to wine, particularly as the best wines were unknown, as must have been the case in northern Germany, the Netherlands, and England. If the wine was harsh and sour, it was still wine, which in favorable years, and even in those latitudes where the crop did excellently well, could be made into a very drinkable beverage. In later times, and when better wines became known, when

the culture of the vine was carried to greater perfection in southern Germany and wine could more easily be carried into northern Germany, the cultivation of the vine must have been given up in regions where favorable years were only the exception. When the first decade of the nineteenth century proved very unfavorable to vine cultivation, a number of vineyards were suppressed even in the best situations, such as Rhenish Hesse and Rheingau, which were afterwards restored with the return of better times, namely, after 1834 and 1835. With the present facilities for communication and the competition in the wine business resulting therefrom vine culture is no longer profitable in many places where thirty years ago it was so; in many places even grain cultivation is declining, because the grain can be procured from a distance cheaper than the cost of cultivation, as is especially the case in Alpine countries. No one would conclude that this is owing to the deterioration of the climate, and with equal right one can not attribute the decline of vine culture in high latitudes, where it is now no longer profitable, to change of climate.

Herodotus describes the fertility of Assyria, notwithstanding that it seldom rains there. No one, he says, could bring himself to believe in its productiveness who was not convinced of it by seeing for himself. At present the fruitfulness of that region is very limited. But Herodotus also describes the excellent irrigation of that country in his time, and Alexander the Great is said to have found on the Scythian frontier an inscription dedicated to Semiramis (2000 B. C.): "I forced the streams to flow where I willed, and I willed only what was useful; I made the dry earth fruitful by watering it with my streams." At the present day the countries in question produce only very meager crops, with the exception of the regions on the Tigris, near Bagdad; in Mesopotamia, near Urfa; in northern Syria, near Aintab, and Messir and other places, where recently irrigation canals have again been laid and magnificent cultivation thereby revived. No change of climate has taken place; human energy alone has altered. Similar changes are seen in Palestine, in Arabia, in Sicily, and many other countries. Should the Chinese in many portions of their country neglect irrigation for even short periods they would quickly see only deserts where now garden cultivation reigns, while the climate would not change in the least. No one acquainted with the true cause would attribute to change of climate the increased productiveness of Lombardy since the restoration of its excellent system of canals and irrigation, or the great decrease of grain culture in Switzerland. Without this knowledge only perverted and false conclusions would be derived.

The diminution of forests in the extreme north of Europe, in Iceland, and in the high Alpine regions is more simply to be explained by the partial deforestation done by the hand of man, rendering the remainder sparser and less capable of resistance to wind and weather than by hypothesis of change of climatic conditions.

At the same time it will not be denied that by irrigation and drainage, by important changes in the system of cultivation, by various natural phenomena of nature, etc., many changes of a climatic character take place. These changes, however, are only local and disappear as soon as the causes which produced them are removed.

Besides, there is in climatic conditions only a moderate stability,

subject to steady and in all probability periodic variations and interchanges, which are difficult to recognize in consequence of the manifold combinations of the numerous effective factors. Climatic changes, extending over long periods of time, are indicated by geological periods, which latter themselves demonstrate again only the gradual and not any sudden alterations of climate. Sudden, and even very moderate slow changes of climate cause the destruction of the vital organism.

The comparison of the climatic conditions of individual years, the differences in the yield of fruits of various kinds, as already mentioned above, the unfavorable years in central Europe at the end of the sixteenth and eighteenth and beginning of the nineteenth centuries, and the very favorable seasons for grain and wine in the last quarter of the seventeenth and at the beginning of the eighteenth century and in the first third of the nineteenth century, together with the recurring failure under similar conditions of crops, particularly of wine, in 1847 and 1881, caused by the cool weather at the end of summer and beginning of autumn, in spite of the hot summer which had preceded it, etc., and furthermore the exact numerical researches based on results of observations of the meteorological elements, all show a variability of climate such as is accomplished within a century, or even within the lifetime of a man, and which can be most positively recognized from year to year, from decade to decade. To find the causes of these changes belongs to those who have devoted themselves to researches in the laws of meteorology, and particularly to discovering the methods by which to prognosticate the conditions of weather for long periods in advance.

Distribution of good and poor wine crops, by decades, since 1600.

[From Fritz (1889), p. 301.]

Decade.	Germany (Rhine).		Switzerland (Zurich).		Decade.	Germany (Rhine).		Switzerland (Zurich).	
	Above average.	Below average.	Above average.	Below average.		Above average.	Below average.	Above average.	Below average.
1600-1609	....	....	1	9	1760-1769	4	6	5	5
1610-1619	....	....	4	6	1770-1779	5	5	7	3
1620-1629	....	....	2	8	1780-1789	5	5	8	2
1630-1639	....	....	4	6	1790-1799	2	8	8	2
1640-1649	1	9	2	8	1800-1809	5	5	5	5
1650-1659	2	8	3	7	1810-1819	4	6	2	8
1660-1669	2	8	5	5	1820-1829	4	6	6	4
1670-1679	3	7	5	5	1830-1839	6	4	5	5
1680-1689	4	6	7	3	1840-1849	3	7	6	4
1690-1699	3	7	1	9	1850-1859	4	6	4	6
1700-1709	5	5	6	4	1860-1869	4	6	6	4
1710-1719	5	5	4	6	1870-1879	4	6	2	8
1720-1729	6	4	9	6	1880-1887	2	6	2	6
1730-1739	3	7	5	5					
1740-1749	6	4	3	7	General average.	3.9	6.0	4.5	5.4
1750-1759	5	5	5	5					

Good and poor wine crops, by years, since 1820.

[From Fritz (1889), pp. 293, 295, 296.]

Year.	Prussia (in Eimers, per morgen).	France (Volnay) (in hectoliters per hectare).	Hochberg, Baden (hectoliters per hectare).	Nikita, Crimea (hectoliters per hectare).	Hesse (hectoliters per hectare).	Ohio (gallons per acre).	Year.	Prussia (in Eimers, per morgen).	France (Volnay) (in hectoliters per hectare).	Hochberg, Baden (hectoliters per hectare).	Nikita, Crimea (hectoliters per hectare).	Principality of Hesse.	Ohio (gallons per acre).
1820	2.03	7					1854	1.93	2	2			
1821	0.69	7					1855	3.82	7	4			
1822	11.19	16	34				1856	3.13	8	3			
1823	5.70	7	56				1857	9.95	22	4			
1824	5.35	7	14				1858	10.75	26	64	12.88		
1825	8.20	6	55				1859	9.07	17	27	12.88		
1826	15.65	32	92				1860	5.94	10	12	13.17		
1827	4.55	22	1				1861	4.62	6	6	8.78		
1828	16.45	29	52				1862	8.92	15		9.66		
1829	5.16	16	33				1863	7.14	17		9.08		
1830	0.80	5	4				1864	5.40	15		11.00	18.7	
1831	3.67	8					1865		17		6.10	28.0	41.8
1832	5.28	10	26				1866		13		13.21	44.3	21.4
1833	10.35	19	55				1867		16		15.23	28.4	39.8
1834	15.43	29	45				1868		27		24.59	46.5	19.1
1835	12.65	33	55				1869		15		28.99	31.7	14.9
1836		18	28				1870		18		13.76	23.6	236.7
1837	4.51	20	14				1871		17		16.46	8.8	91.7
1838	2.74	12	13				1872		7			3.7	24.4
1839	7.06	17	18				1873		7			10.0	10.7
1840	4.24	19	35				1874		15			32.4	106.9
1841	3.25	6	2				1875		27			51.8	24.6
1842	8.05	17	24				1876		15			27.8	63.8
1843	2.33	9	15				1877		10			19.8	59.1
1844	3.93	9	11				1878		10			31.2	80.0
1845	5.36	9					1879		3			9.3	90.3
1846	13.53	21	23				1880		2			3.9	126.0
1847	10.09	22	45				1881		22			36.7	83.0
1848	7.95	22	32				1882		12			13.5	121.0
1849	6.90	13	19				1883		8			33.3	28.0
1850	6.68	11	23				1884		19				
1851	5.57	11	13				1885		10				
1852	7.64	13	15				1886		4				
1853	7.07	10	34				1887		11				

Wheat crop in Ohio, by years, since 1850.

[From Fritz (1889), p. 303. The figures for 1850–1877 refer to the average of two counties, viz, Belmont in the southeast and Erie on the north border of the State. The figures for 1878–1883 are averages for the whole State.]

	Bushels per acre.		Bushels per acre.		Bushels per acre.
1850	17.0	1862	13.8	1874	17.8
1851	14.7	1863	12.8	1875	13.3
1852	14.6	1864	6.7	1876	14.5
1853	11.8	1865	6.8	1877	11.6
1854	9.1	1866	10.5	1878	16.9
1855	15.6	1867	13.0	1879	17.7
1856	11.4	1868	12.9	1880	17.1
1857	10.7	1869		1881	13.8
1858	9.7	1870		1882	15.6
1859	17.0	1871	14.3	1883	16.6
1860	13.8	1872	8.5		
1861	13.4	1873	14.4		

GRASSES.

Relative to the acclimatization of the grasses Spörer (1867) says:

As in the Alps and Himalayas up to altitudes of 15,000 to 16,000 feet, so also in the farthest north, beyond the limit of trees, the grasses flourish. The varieties that compose the grassy carpet of Taimyr are still somewhat numerous. They embrace 10 families and 21 species; about one-half belong to the sour-grass family, the binse or rushes, ried (reed), woold or cotton grass. But fully one-half are the sweet grasses, such as in central Europe are esteemed the best fodder, and not less so in Taimyr Land, where they extend to the shores of the icy Arctic Ocean beyond latitude 75° 30′ north, including among them the "wiesen" or meadow grass, the rispen or ray grass (*Poa pratensis*), and the "rasen schmiele" or turfy hair grass, *Aira deschampsia cæspitosa.* It is not surprising, therefore, that the best milch cattle, the so-called "cholmogor breed," the successors of the cattle transported thither from the Netherlands by the care of Peter the Great, should flourish in the desert polar regions at Mesenja.

The sour grasses, as genuine early spring plants, form their flowers in the previous summer season, and at the beginning of the northern summer (July 10 to 20) are in the fullest bloom and have already turned brown when the sweet grasses begin to show their flower buds.

In general the ground thaws only to the depth of a few inches and the roots do not penetrate into the frozen soil. The tundra of northern Russia and Siberia rests on such a frozen soil; the steppe or prairie or llano rests on unfrozen, deeper, and dryer soil.

The modest circle of plants that surrounds our Arctic Circle is not so complexly constituted under different longitudes as are those of the warmer phenological girdles of the globe; everywhere we have the same species of plants and the same families; everywhere the gramineæ, the cruciferæ, the caryophylleæ, and the saxifragaceæ, are the dominating families, and among the genera the *Draba Saxifraga*, *Ranunculus*, *Carex*, and the meadow grasses; all these

high northern varieties are enduring; only a few of them fail annually to set their fruit and ripen their seed. An annual plant disappears when for a single season it fails to ripen its seed.

A comparison of the flora of Spitzbergen and the high portions of the Alps and Pyrenees shows that the former are the lost children of European flowers that have since the Glacial epoch survived at great altitudes in the mountains as well as in the damp, cold morasses of central Europe.

A comparison of the flora of Taimyr and the mountains of southern Siberia shows that the northern flora has wandered thither and become acclimatized from the southern, and that this process is still going on.

CEREALS.

The elaborate report of Brewer on cereals, in the Tenth Census of the United States, contains the fullest information as to the relation of climate and soil to our cereals. From pages 10 to 27 of this volume I quote the following general remarks:

We may say that, as a rule, in all former times, and until modern means of transportation came into use, the grain most largely consumed for bread in any country or region was the one most easily and most surely grown at home, or at least at no great distance away; the bread, of necessity, had to be made of such grain as could be grown or procured with the facilities then enjoyed. Rye, buckwheat, oats, barley, and millet had among our ancestors an importance as bread plants that they have now lost and will probably never regain. This fact, apparently so obvious and yet so hard to realize in practice, lies at the bottom of that agricultural revolution already alluded to, which is now going on everywhere among nations and peoples of our civilization, and most notably in western Europe.

Seven species (calling buckwheat a cereal) are cultivated in America in sufficient abundance to be returned in the census tables, and three or four more are occasionally cultivated in a few localities. Taken altogether, these include all the more important cereals of the world.

Of the seven species we have to deal with, six are natives of the Eastern Hemisphere and one of the western. No cultivated grain has originated on an island, if we except canary grass, and none in southern Africa or Australia, regions otherwise very rich, botanically, in species. Humboldt called it a striking phenomenon "to find on one side of our planet nations to whom flour and meal from small-eared grasses, and the use of milk, were completely unknown; while the nations of almost all parts of the other hemisphere cultivated the cereals and reared milk-yielding animals. The culture of the different kinds of grasses may be said to afford a characteristic distinction between the two parts of the world."

The genera to which the principal cereals belong are: *Oryza*, or rice; *Triticum*, which includes all the varieties of wheat and spelt; *Avena*, oats of various kinds; *Hordeum*, the various kinds of barley; *Secale*, rye, and *Zea*, Indian corn. Among the true cereals—that is, belonging to the grass family—there are various species of millet, belonging to several different genera (*Panicum*, *Pennicillaria*, *Emilium*, *Setaria*, *Holcus*, and *Sorghum*); durra, a species of *Sorghum*

(called also Indian millet and Guinea corn, and spelled in various ways, as "dura," "dhura," "doura"); canary grass, *Phalaris*, and a few other species belonging to the grasses. In addition to these botanical cereals are the buckwheats, which, for convenience in this report, are classed among the true cereals. They belong to the genus *Polygonum*, two species of which are cultivated in this country, and perhaps others elsewhere. Several species belonging to the genus *Chenopodium* have been cultivated in various parts of the world, particularly in India and central Asia, but none are of importance to European nations as grains. Of a considerable list that might be made, wheat, rice, and Indian corn are the first three in importance; oats, barley, and rye next; then durra, the millets, and buckwheats next; all the remainder being of insignificant importance to the world at large.

However defined and classified, and however used, all the cereals are agricultural grains, all are starchy, all are breadstuffs, and all are annual plants.

Being annuals, they are adapted to almost universal cultivation where the summer climate admits, for "an annual plant may be said to belong to no country in particular, because it completes its existence during the summer months, and in every part of the world there is a summer."

This fact underlies the agricultural importance of the cereals. Every gardener knows that annuals may be brought from almost any country and be made to flourish in cultivation in any other country in which they can complete their life in one summer, and that, even if the summer is too short, varieties may be produced by art which will mature quicker, and then their cultivation may be extended to climates unlike that of their original home. This may be continued up to certain limits set by nature for each species, which limits can be determined only by experiment. Not so with perennials. They must have not only a favorable summer climate, but also a favorable winter climate and a favorable average climate, and, moreover, be able to stand occasional wide deviations from the average climate. The exceptional heat of one year or cold of another, a too wet season or a too dry one, may kill the tree or perennial which has lived and thrived for many years. Hence all perennials are restricted in their growth to very much narrower limits than annuals. Moreover, annual plants are believed to be much more variable under different external conditions than perennials are. They vary more in nature, and it is among the cultivated annual species that we have the widest variation known to science. They can adapt themselves more readily to changes of soil, climate, and other variable conditions than perennials. Thus it is that the plains of Dakota and Manitoba, with their genial summers and fertile soil, even though the winters be of Arctic severity, and California, with its rainless summer, but genial winter, can alike send wheat to the mild-wintered and moist-summered British islands.

Illustrating the first point regarding excellence of seed, both as to its actual condition and its pedigree, there are numerous illustrations recorded; but the famous experiments of Mr. Frederick Hallett, of Brighton, England, may be taken as a good illustration. The experiments were planned with so much intelligence, conducted with such

patience and care, were so profitable in their results—the essential results have been confirmed in so many other ways and by so many practical men—that they are worthy of being quoted in this connection.

He began with a single head of wheat, chosen irrespective of size or vigor, but of a variety producing a good quality of grain. The head was $4\frac{3}{8}$ inches long and had 47 grains, which were carefully planted in rows, 1 grain in a place, 12 inches apart each way. At harvest the plants were carefully compared, and the one with the largest number of heads was chosen, and the grains from the best head of this best plant were planted the next year in the same way; and this was continued year after year, choosing each time for seed the best head from the most prolific plant. At the first harvest the best plant bore 10 heads, at the second 22, at the third 39, at the fourth 52, the best head of which was $8\frac{3}{4}$ inches long and bore 123 grains. (Jour. Roy. Agr. Soc., Vol. XXII, p. 371, and plate.)

This was the origin of the famous "Pedigree wheat." Later, and in a similar way, he made the varieties of "Pedigree oats" and "Pedigree barley," all very prolific, and each becoming famous. He gave the name "Pedigree" to these varieties because his process was precisely analogous to that of improving live stock by breeding to points and strengthening the heredity of the good points by pedigree. Still later he gave his riper conclusions (Trans. Brit. Assoc. Adv. Sci., 1869, p. 113) drawn from his long series of experiments, in substance as follows: That every fully developed plant, whether of wheat, oats, or barley, has one ear superior in reproductive power to any of the others on the plant; that every such plant has one grain more productive than any other, and that this best grain grows on the best ear; that the superior vigor of this grain is transmissible to its progeny; that by selection this superiority is accumulated; that the improvement is at first very rapid, but that in successive years it gradually grows less; that an improved type is the result, and that by careful selection the improvement can be kept up. Another paper on his pedigree system, read before the Farmers' Club at Birmingham in 1874, giving many interesting facts, is republished in substance in the monthly reports of the United States Department of Agriculture for August and September, 1874, page 381.

The practical fact underlying this relates to selection. "Natural selection" is undoubtedly the principle by which species are preserved, whether it accounts for their origin or not, and artificial selection of seed is the only method by which any variety of grain can be improved or even maintained. Without it the variety always either runs out or changes; how rapidly this takes place depends upon various circumstances.

It is unnecessary to multiply further proofs, because all experiment points the same way, and the law is universally recognized. I have merely cited a few out of many scientific experiments. The principle is never denied; it is simply too often neglected in practice. In this connection it is well to remember that it is easier to deteriorate a crop by using bad seed, or even by simply neglecting the selection of the good, than it is to improve an already good variety; the down-hill road is the easiest traveled. The selection of seed to keep up the vigor and the fruitfulness of the varieties cultivated are more

important than fertility of the soil as factors in permanent grain growing. The matter of soil exhaustion is so well known that it is the staple argument with the majority of popular writers and speakers on agriculture; but, so far as I have personally seen or have been able to learn from the observations or the experience of others, in every locality in this country where wheat growing has suddenly risen to large figures the quality and the yield have diminished more rapidly from carelessness in the selection of the seed and in the care of the crop than from mere soil exhaustion.

While there is no absolute proof that any variety of cereal has ever originated in a "sport," nevertheless the indications are that some have so originated. The new variety of Bamia cotton originated in a single plant, entirely unlike its fellows, found in a cotton field in the Nile Valley in 1873, and the variety has already nearly revolutionized cotton culture in Egypt. (McCoan, Egypt as it Is, p. 187, and Kew Rept. for 1877, p. 26, fig. 7.) Cotton is propagated from the seed as the cereals are, but the plant being a more conspicuous one, a sport would be more liable to be noticed. A single cereal plant, unlike its fellows, in a great field of grain would be gathered unnoticed unless some very unusual accident secured its preservation.

It is well known, however, that many varieties of grain have originated in some single plant differing from its fellows found growing in some exceptional place, but how that plant acquired its special characters, whether suddenly, as sports do, or not, we have no knowledge. We simply and only know that here and there some single plant has been found that represents to us a new variety ready made, and varieties have been perpetuated from such plants which have grown true to the seed and which have been valuable and enduring. The variety of oats known as "potato oats" is said to have originated in a single plant found growing in a potato patch (hence the name) in Cumberland, England, in 1778 (Allen, New America Farm Book, p. 163), or, as some say, in 1789 (Stephen's Farmers' Guide, I, 449). This variety, after nearly a hundred years' existence, is still one of the best and brings, it is said, the highest price in the English markets. Its excellence has been proved throughout Europe and entirely across the continent of America, for it is in common cultivation from Maine to Oregon and Washington.

The Clawson wheat originated in a single plant found growing by a stump in the State of New York. Darwin says that the Fenton wheat was found growing on a pile of detritus in a quarry in England. The Chidham wheat originated from an ear found growing in a hedge in the same country, and numerous other examples are recorded in the agricultural literature of this century. It is only fair to say, however, that many varieties of such origin have been rejected on trial as of no value, just as numerous varieties of seedling apples and potatoes are rejected. It is only the few that are actual improvements on what we had before. In ornamental and other garden plants the tendency to "sport" is much increased by crossing varieties, and this is probably also true of all classes of cultivated plants.

Using seed which has been grown in some other locality, or, as farmers say, "a change of seed," has been practiced by grain growers in all ages; and that this is very often attended with an increase of

crop has been proved by the experience of centuries. Sometimes this change of seed means bringing in a variety previously cultivated there by bringing it from some other place more or less distant.

To illustrate: Potatoes grow well as far south as Louisiana, the Bermudas, and other warm climates, if the seed is yearly brought from a cooler region. The same fact is true of peas, and there are large importations of seed peas from Canada to the United States every year. Most garden vegetables behave in a similar way, and on this fact the modern business of growing garden seeds is largely founded. In Connecticut, onion seed is imported from Tripoli. The first crop grown from this seed is of such excellent quality that the trouble and expense of the importation are justified; but if the cultivation is continued from seed produced by the American crop, in a few years the onions degenerate to the size of acorns. The constant sending of the seeds of squashes and other garden vines from the New England States and other places east of the Appalachians to the fertile prairie soils of the West is another familiar illustration, and similar facts have been observed all over the world. Melon seeds from Tibet are taken every year to Kashmir, and produce fine fruit weighing from 4 to 10 pounds; but vines growing from the seed of melons produced thus in Kashmir yield the next year fruit weighing but 2 or 3 pounds. Seed of the sea-island cotton have been carried to every cotton-producing country of the world, but the variety rapidly degenerates in every place yet tried distant from its original home, and if the excellency of the fiber is kept up elsewhere it is only done by the use of fresh seed.

Now, it often happens that such a variety, specially prepared for a region by a long process of adaptation, may be better suited to it than any new one, and in such cases no increase of crop follows a change of seed. For example, heavy oats taken from the cool, moist climates of Canada or northern Europe, used as seed in the northern or middle United States, usually produce at first a crop weighing more per bushel than that produced from home-grown seed. But in various places, notably so on Long Island, where special varieties have long been grown from seed carefully selected as to weight until this weight reaches that which is produced from foreign seed, no increase of weight is obtained by any change of seed. This appears to be the case in several localities reported. Another example to the point is in the local varieties of corn sometimes cultivated on farms in New England and the Middle States. Where a single variety has been cultivated for a man's lifetime in the same neighborhood, or even on the same farm each year, the seed having been carefully selected and prepared until no further improvement is reached by such selection, here it often happens that such home-bred local variety yields better than any variety introduced from without. But it also happens that, having been so long purely bred, it is of especial value in mixed planting, as already described.

COTTON.

H. Hammond, in his report to E. W. Hilgard on the cotton production of the State of South Carolina (Tenth Census U. S., 1880, Vol. VI, p. 475), says:

In a handful of ordinary cotton seed three varieties may often be recognized, presenting well-marked differences. The largest of these is covered with a green down; another smaller and much more numerous seed is covered with a white or grayish down; the third variety is naked, smooth, and black. It may not be possible to say whether these three sorts of seeds correspond to three classes under which the numerous varieties of cotton are arranged. These are, first, the "green seed,' corresponding with the *Gossypium hirsutum*, or shrub cotton, attaining a height of from 10 to 12 feet, a native of Mexico, and varying as an annual, biennial, or perennial, according to the climate in which it is grown; second, the "white seed," corresponding with the *Gossypium herbaceum*, or herbaceous cotton, an annual, attaining a height of 2 feet, native of the Coromandel coast and the Nilgherries; third, the "black seed," corresponding with *Gossypium arboreum*, or tree cotton, a native of the Indian peninsula, but attaining a height of 100 feet on the Guinea coast, and producing a silky cotton. The black seed, however, is not distinguishable from the seed of the long-staple or sea-island cotton.

HISTORY OF THE LONG-STAPLE COTTON.

It would be a matter of much interest to determine the origin and history of the varieties of cotton now in cultivation. The difficulties of doing this are much increased by the very wide geographical range occupied by the plant. The earliest explorers, Columbus, Magellan, Drake, Captain Cook, and others, seem to have found it almost everywhere in the broad belt extending from the equator to 30° south and to 40° and 45° north latitude, where it now grows. Although it is not found among those oldest of vestments, the wrappings of Egyptian mummies, its use was known to man in Europe, Asia, Africa, America, and the outlying islands of the sea in the remote past, far beyond the historic age. Its very name itself bears evidence to this, occurring, as it does, in many and in the most ancient languages.

Nevertheless nothing can show more clearly the importance of tracing and understanding the history of plants under cultivation than the variation and improvements in black seed cotton since its introduction on the Carolina coast. It is known that the first bale of long-staple cotton, exported from America in 1788, was grown on St. Simons Island, Georgia, by a Mr. Bissell, from seed that came from either the Bahamas or the Barbadoes Islands.[a] Singularly enough, the authorities leave this matter in doubt, the Hon. William Elliott saying it came from Anguilla, one of the Bahamas,[a] and Signor Filippo Partatori (Florence, 1866), saying it came from Cat Island, one of the Barbadoes.[a] But as Anguilla is one of the Barbadoes[a] and Cat Island one of the Bahamas[a] it would seem difficult to decide to which group of islands we are indebted for these seed. However, as Mr. Thomas Spalding, of Sapelo Island, says, in a letter to Governor

[a] Sic.

Seabrook, in 1844, that three parcels of long-stapled cotton seed were, to his knowledge, brought in 1785–86 from the Bahamas to a gentleman in Georgia, it would seem certain that the seed reached our coast from those islands. There it was known as *Gossypium barbadense*, as coming from the Barbadoes. In the Barbadoes it was called Persian cotton, the seed having been brought from that country. In this manner its descent from the *G. arboreum* of India is traced.

Be this as it may, Mrs. Kinsey Burden, Burden Island, Colleton County, S. C., obtained some of these seeds from Georgia and planted them. This crop failed to mature, and the first successful crop of long-staple cotton grown in South Carolina was planted in 1790 by William Elliott, on the northwest corner of Hilton Head, on the exact spot where Jean Ribault landed the first colonists and erected a column of stone, claiming the territory for France a century before the English settled on the coast. Mr. Elliott's crop sold for 10½d. per pound. Other planters made use of this seed, but it was not until Kinsey Burden, sr., of Colleton County, began his selections of seed, about the year 1805, that attention was strongly called to the long staple. Mr. Burden sold his crop of that year for 25 cents per pound more than did any of his neighbors. He continued to make selections of seed and to improve his staple, and in 1825 he sold a crop of 60 bales at $1.16 per pound. The year subsequent his crop sold for $1.25, and in 1828 he sold 2 bales of extra fine cotton at $2 per pound, a price not often exceeded since. The legislature was on the point of offering Mr. Burden $200,000 for his method of improving the staple of cotton, and Mr. William Seabrook, of Edisto, was prepared to pay him $50,000 for his secret, when it was discovered that the fine cotton was due wholly to improvements made in the seed by careful and skillful selection. Since then the greatest care has been bestowed upon the selection of the seed, and to such perfection was the staple brought by this means that the crops of some planters were sold not by sample, but by the brand on the bale, as are the finest wines.

During the war of 1861–1865, the cultivation of the finest varieties being abandoned on the islands, the seed removed to the interior greatly deteriorated in quality. So scarce, on this account, was good seed directly after the war that J. T. Dill, a cotton merchant in Charleston, at one time had, in an ordinary letter envelope, the seed from which are derived all the better qualities of long staple now cultivated. Nor have the improvements made by careful selection of the seed ceased in later years. The staple has kept fully up to the best grades of former days, and the proportion of lint to seed cotton has been increased. Formerly 1 pound of lint cotton from 5 pounds of seed cotton of the fine varieties was considered satisfactory. Thanks to the efforts of Mr. E. M. Clark, a cotton has been recently found which yields 1 pound of lint to 3½ of seed cotton, preserving at the same time the length, strength, and evenness of fiber characteristic of the best varieties.

BEANS.

The history of the derivation of the bean (*Vicia sativa*, *Vicia faba*, and *Ervum lens*) is given by A. de Candolle (see Agr. Sci., Vol. I, p. 58), who shows that its cultivation began in Persia, and that the common white bean, which has been cultivated since prehistoric times

in Europe, has some similarity to a bean cultivated in India since the earliest times. The characteristic peculiarities of the cultivated bean and its uncultivated relatives have probably existed for at least five or six thousand years, and the original stock from which the cultivated bean was derived has long since become extinct.

PEPPER.

The derivation and varieties of peppers from all parts of the world (genus *Capsicum*) are described by E. L. Sturtevant (Agr. Sci., Vol. II, p. 1). The general effect of climate is to diminish the size of the fruit when the seeds are planted in higher latitudes—that is to say, with a diminution of temperature. Similarly, the effect of cold nights is to check the growth, diminish the size, and promote early ripening.

KENTUCKY BLUE GRASS.

The germination of Kentucky blue-grass seed (*Poa pratensis*), as also that of red top and timothy, has been studied by Thomas F. Hunt at the agricultural experiment station, Champaign, Ill. Although the object of the experiment was primarily to determine the relative vitality or honesty of the seeds and samples from different sources, yet the results have some bearing upon the question as to the best temperature for germination and the possibility of acclimatization. Kentucky blue grass, raised in Kentucky, when sown in the Geneva sprouting apparatus, would not germinate in thirteen weeks at temperatures from 70° to 80° F., whereas 80 per cent of meadow fescue and 95 per cent of mammoth red clover sprouted during the first week in June, 1888. Again, in 1889 a specimen of blue grass from the same locality would not sprout in sixty days at an average temperature of 67° F., whereas during the first eight days 98 per cent of both timothy and red clover and 85 per cent of meadow fescue sprouted. Again, a sample from another dealer in Kentucky, tested for thirty days under similar conditions as the last, gave one sprout to a hundred seeds. Another sample was sent from Chicago to Manitoba and thence to Champaign for testing. Out of 500 seeds not one sprouted, but in the best of subsequent samples 7 per cent sprouted.

Finally, samples were obtained from 19 different sources, mostly in Kentucky, and were all tested uniformly in the Geneva apparatus at Champaign, Ill., from July 23 to August 31, 1889. The range of temperature in the apparatus was from 63.5° to 73.5° F. Out of all

the samples the maximum and the minimum percentages of sprouting were as shown in the following table:

Variety.	Maximum.	Minimum.	Average of 19.
	Per cent.	*Per cent.*	*Per cent.*
Kentucky blue grass	7	0	2
Red top	63	4	25
Timothy	96	42	76

These are not likely to be abnormal percentages, since, according to Professor Hunt's calculation, with an ordinary seeding of 30 pounds to the acre, if only 2 per cent germinates there would be 40 plants to the square foot. But the question may still remain as to whether the soil or the temperature were unfavorable or whether the seed of the Kentucky blue grass was in some abnormal condition. (Agr. Sci., Vol. IV, p. 4.)

Chapter XII.[a]

RELATIONS OF SPECIAL CROPS TO SPECIAL FEATURES OF CLIMATE AND OTHER INFLUENCES.

The preceding chapter on phenology has given several illustrations of the influence of the date of planting upon the dates of the resulting phases and on the amounts of the harvest for special plants. The experiments at experiment stations now about to be quoted were undertaken with a view to the further direct elucidation of this relation. From such experiments we obtain definite data by which to decide as to the best date for planting and the probable resulting crop both in normal and abnormal seasons. We see to what extent the seed and plant have acquired habits suitable to the prevailing climate, and furthermore, what climatic influences the plants were not able to withstand when the seeds were planted too early or too late. It is, of course, of prime importance in each case to know where the seeds were grown or to what climate they were acclimatized before being planted at the experiment station.

By measuring the weight and nutritious value of a sample of a crop at various stages of development we are able to form tables showing the relation of the mature ultimate harvest to the immature plant, and this relation is found to be sufficiently constant to justify one in predicting the harvest per acre from its condition on any given day several months before harvesting. Examples of this process have already been given and others now follow.

BEETS AND POTATOES.

DATE OF PLANTING.

Briem finds the crops of beets and potatoes that have become acclimatized in Austria-Hungary vary with date of planting, as given in the table following.

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[a] A chapter on "Forests and climate," which was originally intended to precede this chapter, is omitted.

Date of sowing.	From sowing to harvest.[a]				Average weight of one tuber.	
	Number of days.	Sums of mean daily temperatures.	Number of days when rain fell.	Total rainfall.	Beet.	Potato.
		° C.		mm.	Grams.	Grams.
March 1	234	3,271	108	519	298	196
March 16	219	3,209	108	506	231	222
April 1	203	3,151	102	496	207	272
April 16	188	3,020	94	453	304	257
May 1	173	2,881	87	417	306	302
May 16	158	2,726	80	373	266	228
June 1	142	2,469	68	294	211	217
June 16	127	2,197	55	169	82	173
July 1	112	1,890	48	154	75	158
July 16	97	1,627	37	122	52	86
August 1	81	1,331	31	99	14	47
August 16	66	1,026	35	76	13	22

[a] Harvest October 20.

SUGAR BEETS.

Durin has shown that the sugar beet loses the sugar in the root by its consumption in forming stalks and leaves as well as seeds. The roots die when all the sugar is used up, from which I infer that the best time for gathering the beets must be at that period of ripeness in which the formation of leaves ceases, and possibly this formation of leaf and loss of sugar can be checked artificially by cutting the young leaves. (Agr. Sci., Vol. IV, p. 326.)

GRASSES.

The changes in the chemical composition of grass and in the nutritious quality of the dried hay have been determined by E. F. Ladd (Agr. Sci., Vol. I, p. 221) by experiments on timothy (*Phleum pratense*), who concludes as follows:

(1) The amount of water in timothy diminishes rapidly.

(2) There was a large increase in crude fiber in late-cut timothy over that cut at the period of full bloom.

(3) As the grass approached maturity there was a considerable diminution in the percentage of sugar and an increase of the starch.

(4) After the period of full bloom the proportion of albuminoids to the other organic constituents diminished.

* * * * * * *

(8) Finally, from a chemical point of view, it seems preferable to cut timothy for feeding at the period of full bloom, rather than after the seeds have formed. (Agr. Sci., Vol. I, p. 223.)

The effect of climate on the yield and chemical composition of

grasses, especially the pasture grass, has been studied at the Pennsylvania State College Agricultural Experiment Station, by G. L. Holter (Agr. Sci., Vol. III, p. 285), in connection with studies on the yield per acre. Samples of grass were cut every few days during the season (of 1887), but the comparisons with rainfall and temperature showed no definite relation, except, perhaps, that the percentage of ash increased as the temperature diminished. The following table gives the figures showing the average rainfall and temperature from the middle of one period to the middle of the next, and for the average of seven plats of ground:

Period.	Rain-fall.	Tem-pera-ture.	Yield per acre, in pounds.		Period.	Rain-fall.	Tem-pera-ture.	Yield per acre, in pounds.	
			Fresh grass.	Dry hay.				Fresh grass.	Dry hay.
	Inches.	°*F.*				*Inches.*	°*F.*		
May 5-22	....	....	1,300	339	Aug. 29-Sept. 5	0.88	66.5	147	38
May 25-June 4	2.62	61.0	525	130	Sept. 10-14	1.56	60.2	216	52
June 6-12	0.52	62.2	325	91	Sept. 18-21	1.50	60.4	202	53
June 13-22	0.23	70.0	140	41	Sept. 22-29	0.41	60.2	84	24
June 25-July 2	1.75	75.3	229	65	Sept. 29-Oct. 2	0.39	55.9	85	21
July 3-11	0.51	67.2	171	50	Oct. 15-17	0.85	45.2	32	11
July 13-20	1.74	67.9	247	67	Oct. 17-22	1.42	46.1	43	16
July 21-29	0.72	69.2	170	45	Oct. 30-Nov. 5	1.37	45.6	9	3
July 30-Aug. 7	0.25	75.2	101	34	Total	....	....	4,277	1,145
Aug. 8-20	1.48	72.6	105	23					
Aug. 22-28	3.24	68.6	145	43					

If we assume that the whole season extended from May 10 to September 29, we may compute the average daily growth, which will be found to be very large at first, but rather uniform from June 13 to September 16, after which it steadily diminishes. The irregularities in the growth from one week to the next have no simple connection with rainfall or temperature, but there is no evidence to show that other climatic elements, such as sunshine and evaporation, would not have thrown some light upon the subject.

Mr. Holter has also experimented on the yield per acre of pasture grass, as measured week by week during the growing season of 1888 and 1889 at the Pennsylvania State College Agricultural Experiment Station. (See Agr. Sci., Vol. V, p. 52.) The plat experimented upon represents an average of the uplands of the Allegheny Mountains. The weather of the season was most favorable for the growth of grass, having a heavy, evenly distributed rainfall. The following table shows the dates of cutting and the average daily growth between these dates, expressed in pounds of dried grass per acre. It will be seen that there was a rapid increase in growth up to May 21, after which there was a steady decline. The daily average for the whole season of one hundred and seventy-eight days

is 32.13 pounds of fresh matter and 9.06 of dry matter. Evidently a pasture that is fairly well stocked with cattle in May and June will be overstocked in August and September.

Date of cutting.	Weight of dry matter.	Date of cutting.	Weight of dry matter.	Date of cutting.	Weight of dry matter.
	Pounds.		*Pounds.*		*Pounds.*
April 20	0.00	June 17	13.26	August 9	8.53
May 1	4.86	June 22	13.04	August 16	7.95
May 9	8.69	June 28	9.78	August 23	8.48
May 15	15.93	July 5	13.41	August 29	5.78
May 21	20.01	July 11	8.77	September 9	4.65
May 24	15.29	July 17	9.74	September 23	5.35
May 29	12.48	July 23	11.46	October 4	4.32
June 5	12.81	July 29	9.79	October 15	1.78
June 11	13.49	August 3	13.91		

CEREALS.

C, Richardson (Agr. Sci. Vol. I, p. 125) states that the quality of the grain produced in any locality is dependent principally on three conditions—the climate, the soil, and the cultivation. Wheat is most susceptible to its environments; thus the Atlantic slope produces a wheat grain of medium size and with less than the average amount of nitrogenous constituents. In this part of the country latitude exerts a minor influence.

In the Central States—Tennessee, Kentucky, Arkansas—the grain is larger and contains more nitrogen.

In the Northwest a grain is harvested smaller than anywhere and richer in nitrogen.

In Colorado, where irrigation is practiced, a large grain is grown which is rich in nitrogen.

On the northwest Pacific slope the grain is large, very starchy, and with less nitrogen than anywhere else.

The above conditions, as at present existing, are probably in a state of transition.

The following table shows the difference in the composition of the crops of standard varieties of wheat in Minnesota and Dakota:

Crop.	Albuminoids.	Crop.	Albuminoids.
	Per cent.		*Per cent.*
1882	13.21	1884	14.28
1883	15.14	1885	15.99

The following table shows the differences for the varieties raised in the respective States:

	Weight of 100 kernels.	Albuminoids.		Weight of 100 kernels.	Albuminoids.
	Grams.	*Per cent.*		*Grams.*	*Per cent.*
All North America	3.644	12.15	Ohio	3.476	12.83
Atlantic slope	3.489	11.35	Tennessee	3.150	12.50
Central States	3.684	12.66	Kentucky	3.454	13.15
Northwest	3.205	14.07	Virginia	3.438	12.10
North Pacific	4.091	9.73	Georgia	3.579	11.78
Canada	3.325	10.87	Alabama	3.424	11.29
Michigan	3.969	11.67			

The effect of climate and soil on wheat is strikingly shown in that a soft plump yellow wheat from Oregon and a small hard red variety from Minnesota, when used as seed in Colorado, in three years' time had lost nearly all their differences, so as to look more like Colorado grain than like their own originals.[a]

A study of 38 varieties grown during seven years on one farm in Colorado shows a progressive change, as in the following table:

Year.	Weight of 100 grains.	Albuminoids.	Weight per bushel.	Year.	Weight of 100 grains.	Albuminoids.	Weight per bushel.
	Grams.	*Per cent.*	*Pounds.*		*Grams.*	*Per cent.*	*Pounds.*
1881	4.865	13.40		1884	4.222	12.53	65.2
1882	4.283	13.04		1885	3.810	11.34	62.2
1883	3.941	11.74					

These determinations show plainly that the soil and other conditions in 1885 would not produce as good a crop from introduced seed as in 1881, and that the drop in character of the crops as a whole is due as much or more to soil than to season. The seven varieties grown for several years in Colorado which showed no signs of deterioration are on this account worth considering, since they are perhaps the varieties to select for the locality, because they may be more suited to the conditions there existing than any others. Attention is called to the fact that deterioration in quality, as evidenced by diminution of albuminoids, is shown by the loss of weight per bushel. In the present case a drop of 1.2 per cent in albuminoids was accompanied by a loss in weight of 3 pounds per bushel. No other cereal seems to be influenced by its environment in the same way as wheat. Oats are more changed, by climate and soil, in the outward physical appearance and properties of the grain; barley is modified in its

[a] There is nothing to show how much this may have been due to spread of pollen from one field to the other.—C. A.

chemical composition; maize is modified as to its size; rye varies very little with change of conditions, except as to the effect upon the straw; but, as we have seen, wheat changes both its external appearance and its chemical constituents.

With regard to maize, the high ripening temperature of the Southern States appears to diminish the size of the kernel and prevent a large formation of starch. But the variations in size peculiar to the varieties are much smaller than variations that are due to the climate and soil, thus Dent varieties of corn from Tennessee and Indiana have been found weighing, respectively, 64.1 and 13.9 grams per 100 kernels, or a ratio of 5 to 1 in the weights of the kernels. Hence a comparison of the yield per acre by the weights of the crops would differ very much from a comparison by volumes in bushels. The percentage of albuminoids varies very much less in the large and small kernels of maize.

As to oats, the climatic surroundings cause a very large variation in their physical appearance. The extreme weights per bushel are 48.8 and 24.7 pounds; the extreme ratios in the weight of the kernel, with reference to the weight of the kernel plus the hull, are 79 and 55 per cent. The average composition all over the country as to the percentage of albuminoids is between 12 and 10 per cent, except in a few extreme cases of 9 and 19 per cents, which are as liable to occur in one locality as in another.

Barley is not as variable in composition and appearance as wheat and oats; the extreme weights per bushel are 60.2 and 50.4 pounds, and the extreme weights of 100 kernels are 4.900 and 2.630 grams; the extreme percentages of albuminoids are 14.88 and 8.75. For malting purposes the large quantity of albuminoid is not desirable, while starch is desirable.

WHEAT—GENERAL RELATIONS TO CLIMATE AND SOIL.

In his tenth census report Professor Brewer says:

While the cultivation of wheat in a commercial sense is determined by a complicated set of conditions, in an agricultural sense the matter is very much simpler. The yield and quality of the crop practically depends upon but five conditions—the climate, the soil, the variety cultivated, the method of cultivation, and the liability to destruction by insects. Even under poor cultivation and exemption from insect depredations, if the other three conditions are favorable good crops of wheat of good quality may be very often grown, and in a good climate and with a good variety of wheat an excellent quality may be grown even where the soil is comparatively poor. The yield may be small, but the grain itself will be good.

As regards soils, we may say in a general way that light clays and heavy loams are the best for wheat. On the one hand, very heavy

clays often produce good crops, both as to yield and as to quality, and on the other hand the lighter soils may yield a good quality. It is simply smaller in quantity. The best crops, however, come from moderately stiff soils, but any fertile soil will produce good wheat if all the other conditions are favorable.

Geologically considered, the most of the wheat grown in the United States is over the region of drift, but much of the wheat soil has been so modified by other geological influences that the geological factor is not an important one, the essential character which gives it its value being as largely physical as chemical. Good wheat lands agree in this, that they are sufficiently rolling for natural drainage; are at the same time level enough to admit of the use of field machinery, and are easily tilled, admitting the use of light field implements in their tillage and thus allowing of a very large production of grain in proportion to the amount of human labor employed. The facility of putting in the crop and harvesting it is really the controlling condition in many localities, so much so that the very important wheat regions, where some of the most speculative farming of the United States is practiced, are in regions where the climatic conditions are such that the average yield one year with another may be as low as 10 bushels per acre. In such cases this low average is usually due to climatic reasons rather than to a lack of fertility in the soil, and in favorable years the yield may be very much larger. The ease of cultivation, the facilities for gathering the crop, and its good qualities in favorable years incite to the hope that all years will be favorable, and in good years the profits are large. In color, in the amount of clay contained, in physical and in chemical characters, there is much difference in the different soils of the country. Some contain much vegetable matter, others but little. We may say that the soils of all the more important wheat regions (so far as we have chemical analyses) are rich in lime, as well as in those other elements of fertility, such as potash and phosphoric acid, which are necessary for a good crop and a good quality of grain.

For commercial as well as for agricultural success climate is an all-controlling condition. Wheat is normally a winter annual. For a good crop the seed must germinate and the young plant grow during the cool and moist part of the year, which season determines the ultimate density of growth on the ground and, consequently, mostly determines the yield. Wheat ripens in the warmer and drier parts of the year, which season more largely determines the quality, plumpness, and color of the grain. In climates with winters so cold that all vegetable growth is suspended we have two distinct classes of varieties, known, respectively, as spring and winter wheats. Throughout all the Northern States, from ocean to ocean, and to some extent in those Southern States which lie east of the Great Plains, these two classes of varieties are very distinct as regards their cultivation and to some extent also as regards their characters. In California and in similar climates, as in Egypt, this distinction does not exist in respect to their cultivation, although the varieties partake more of the character of winter wheats than of spring, both in their mode of growth and in the character of the flour made from them.

But in all climates and whatever variety may be grown, the crop must be sown and have its early growth in a cool part of the year.

Wheat branches only at the ground, and produces no more heads than stalks. It only sends out these branches early in its growth or during cool weather and when the growth is comparatively slow. The branching of wheat (called "tillering" in the Old World, and "stocking," "stooling," and "tillering" in different sections of this) must take place before the plant attains any considerable height or it does not occur at all. Hence, in climates like those of the Northern and Eastern States this takes place mostly in the spring, and a cool, prolonged, and rather wet spring is therefore best for the ultimate yield of the crop; the grain then stands heavier on the ground. On the contrary, a warm, rather dry, rapidly growing, and early spring in those parts of the country diminishes the yield of wheat, because of this habit of growth; there are then fewer stalks, and the heads are fewer. Consequently, when from the nature of the season or the general climate of the region there is an undue tendency for the wheat to shoot up without sufficient branching it is common to check the growth by pasturing off the grain in the early spring, as is a common practice in many of the Southern States.

In a country of cold winters, for good crops it is better that the ground be continuously covered with snow. Bare ground, freezing and thawing, now exposed to cold and dry winds and now to warm sunshine, is exceedingly destructive to wheat. It "winter-kills" in two ways—what may be frozen to death by cold, dry winds, or, as is more often the case, particularly on soils rich in vegetable matter, it "heaves out," and by the alternate freezing and thawing of the surface soil the roots are lifted out of the soil and the young plant perishes. The means of guarding against this or of lessening the danger will be spoken of later.

After the wheat comes in head more sun is needed and less rain. Too much rain, particularly if accompanied with heat, induces rust, mildew, and other diseases, and, on the other hand, too dry winds shrink the grain.

The ideal climate for wheat is one with a long and rather wet winter, with little or no frost, prolonged into a cool and rather wet spring, which gradually fades into a warmer summer, the weather growing gradually drier as it grows warmer, with only comparatively light rains after the blossoming of the crop, just enough to bring the grain to maturity, with abundant sunshine and rather dry air toward the harvest, but without dry and scorching winds until the grain is fully ripe, and then hot, dry, rainless weather until the harvest is gathered. This ideal is nearer realized in the better years in California than in any part of the United States, and it is there in such years that we find the greatest yields known to the country.

The quality of the grain is largely determined by the climate, a hot, dry, and sunny harvest time being best for wheat of the first grade. The berry is then brighter, and millers say the quality is better if the climate has been hot and dry before the harvest. The wheat of sunny climates—those of California, Egypt, northern Africa, and similar countries—has always ranked high for quality, and the statement is often made that the wheat of such climates is also richer in gluten—that is, makes stronger flour—than the wheat of cooler climates. Of this latter assertion I find no proof from the modern and fuller chemical analyses. The chemical composition depends

more upon the variety cultivated than upon either soil or climate. The spring wheat of Dakota and Minnesota produces as strong flour as does grain from a sunnier climate. It is true that certain varieties of very hard wheats only grow in hot, dry climates. Such is said to be the case with the best macaroni wheats. It is claimed that the macaroni wheats of California are equal to the best of northern Africa or of southern Europe and that the macaroni made from it in San Francisco is equal to the best Italian. But while, as a whole, the quantity of gluten and the strength of the flour is determined more by the variety of wheat than by the climate or the soil, yet both of the latter have their influence on chemical composition. Although direct chemical evidence is lacking, derived from a large number of chemical analyses from samples chosen with this special object in view, it is claimed that abundance of phosphates in the soil increases the quantity of gluten in the crop. The millers of western New York say that the flour has grown stronger with the increase in the use of superphosphates in growing wheat in that region, and that the same has often been stated as a fact in English experience.

The particularly bright character of American grain, however, depends upon the climate rather than upon the soil. The sunny climate of the whole United States south and west of New England is favorable for this, and from the time of the first settlement of the colonies the bright color of American grain, as compared with that of northern Europe, particularly that of Great Britain, has been remarked.

The table of distribution according to annual temperature (Tenth Census, Cereals, Table XIX, p. 14) shows that the greatest production is where the mean annual temperature is between 50° and 55°, 173,895,149 bushels, or 37.8 per cent, being grown in this belt, and 136,401,822, or 29.7 per cent, where the mean annual temperature is between 45° and 50°. Adding these two, we see that 310,296,971 bushels, or 67.5 per cent, is grown where the mean annual temperature is between 45° and 55°. Considered in respect to the midsummer or July temperature (Table XX, p. 14), which has much to do with the ripening of the grain, our figures are of less interest in this crop, because over considerable regions of the country the crop is already ripe before July begins, notably in California; but we find that 223,852,371 bushels, or 48.7 per cent, grows where the mean temperature of July is between 70° and 75°, and 178,530,037 bushels, or 38.9 per cent, where the midsummer temperature is between 75° and 80°, or an aggregate of 87.6 per cent where the July temperature is between 70° and 80° and 97.3 per cent where it is between 65° and 85°. While the ideal climate for wheat is one of mild winters, and some of the most noted wheat regions of the world are where snow and frozen ground are unknown or very rare (as in Egypt, India, and California), nevertheless most of the wheat of the world grows in regions of cold winters.

The table of distribution according to mean winter temperature (Tenth Census, Cereals, Table XXI, p. 15) shows that in this country 46.6 per cent grows where the mean January temperature is between 20° and 30°, 68.9 per cent where it is below 30°, and it is safe to say that 70 per cent of the wheat crop of the country is grown where the

average January temperature is below the freezing point. This same condition marks most of the great wheat regions of the world.

The wheat countries (which are also the countries of oats, barley, and rye) are where the summer season only is the growing season, and the comforts of winter must be provided for by forethought and labor; and hence they are also the countries of labor, industry, and enterprise, and where the highest civilization has been developed, the result being correlated to these climatic conditions.

The table of distribution according to rainfall (Table XXII, p. 16) shows that 132,152,234 bushels, or 28.8 per cent of the crop, grows with an annual rainfall of between 40 and 45 inches, 62.7 per cent where it is between 35 and 50 inches, and 92.4 per cent where the annual rainfall is above 25 inches, although some important wheat regions, notably those of California, are where the mean annual rainfall is less than 25 inches. We have an explanation of this in the seasons at which the rain falls. The table of distribution according to the rainfall of the growing season (Table XXIII, p. 16) shows that 220,656,637 bushels, or 48 per cent of the crop, grows where from 20 to 25 inches of rain falls during this season, and 366,381,658 bushels, or 79.7 per cent, where the rainfall during the growing season is from 15 to 25 inches, 6.4 per cent where it is below 15 inches, and only 1 per cent where it is less than 10 inches—a fact of much significance for great tracts of our country.

CULTIVATION OF CEREALS—EXPERIMENTS AT BROOKINGS, S. DAK.

WHEAT.

The first annual report of this station, for the year ending June 30, 1888, gives following table of results of experiments on different varieties of wheat, at Brookings, S. Dak. (lat. 44.3° N.; long. 98.5° W.), in April and May, 1887, on plats of ground that had already borne one crop of wheat or flax or oats. Some were sown broadcast and had no subsequent cultivation; others were "drilled by hand" and subsequently hoed twice or thrice.

The columns giving the calculated sums of degrees of temperature are based upon observations at the Signal Service station at Huron, some distance to the westward, because the special station at Brookings was not then established. The meteorological table for Huron follows the agricultural tables, so that the student may make such further studies as he desires. A fragment of the meteorological record at Brookings for 1888 is given in the station Bulletin No. 5, which I have compared with the record for Huron and find that no important error will result from using the Huron records.

Variety.	Date of sowing.	Date of harvesting.	Sums of positive temperatures (T-43° F.).
Sown broadcast:	1887.	1887.	° *F.*
Saskatchewan Fife	Apr. 25	Aug. 1	2,367
French Imperial	...do...	July 29	2,279
Hand drilled:			
Blount, Colorado	Apr. 30	Aug. 10	2,513
Wellman's Saskatchewan	...do...	Aug. 9	2,484
Pure Scotch Fife	...do...	Aug. 6	2,397
Russian Fife	May 3	Aug. 11	2,514
China Tea	...do...	...do...	2,514
Velvet Chaff or Blue Stem	...do...	July 29	2,168
Blount's Hybrid, No. 15	Apr. 30	Aug. 9	2,484
Blount's Hybrid, No. 17	May 3	Aug. 6	2,373
Champlain	May 8	Aug. 8	2,311
Golden Drop	May 3	Aug. 4	2,326
Blount's Rust Proof	...do...	Aug. 8	2,437
Peerless or Black Bearded	...do...	Aug. 20	2,728
Pringle's Grandee	...do...	Aug. 12	2,534

BARLEY.

The following table gives the results of experiments on different varieties of barley at Brookings, S. Dak., as given in the first annual report of that station. For further details see the preceding section on wheat experiments.

Variety.	Date of sowing.	Date of harvesting.	Sums of positive temperatures (T-43° F.)
Sown broadcast:	1887.	1887.	° *F.*
Scotch	Apr. 25	July 18	1,977
Chevalier	...do...	July 23	2,095
Wisconsin Manshury	...do...	July 18	1,977
Imperial Hybrid	...do...	...do...	1,977
Hand drilled:			
Manshury	May 5	July 23	1,946
Two-Rowed	...do...	July 22	1,922
Melow	...do...	July 20	1,880
Imperial	...do...	July 25	2,010
Four-Rowed	...do...	...do...	2,010
Barley No. 3	...do...	July 20	1,880
Black Hulless	...do...	July 28	2,099

The following table gives the results of experiments on different varieties of oats at Brookings, S. Dak., as given in the first annual report of that station. For further details see the preceding section on wheat experiments.

Variety.	Date of sowing.	Date of harvesting.	Sums of positive temperatures (T−43° F.).
Sown broadcast:	1887.	1887.	°F.
Probstier	Apr. 23	July 29	2,279
Welcome	Apr. 25	....do...	2,279
White Belgium	....do...	Aug. 1	2,367
Wide Awake	....do...	Aug. 3	2,319
White Bonanza	Apr. 26	Aug. 1	2,365
Hargett's White Seizure	....do...	July 22	2,069
Hand drilled:			
White Victoria	May 5	Aug. 3	2,270
Black Norway	....do...	Aug. 8	2,399
Black Tartarian	....do...	....do...	2,399
Dakota Chieftain	....do...	Aug. 1	2,218
No Name	....do...	....do...	2,218
Golden Russian	....do...	July 28	2,099
White Surprise	....do...	Aug. 1	2,218
Holstein	....do...	....do...	2,218

The meteorological record for the "growing season" of 1887 at Huron is now given for detailed comparisons. The last three columns give the temperatures computed by the two methods of Boussingault and Angot, respectively.

Meteorological data for Huron, Dak., in 1887.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Positive temperature (T −43° F.).	Sum of daily temperature. All.	All above 43° F.	All positive (temperature above 43°F.).
1887.	°F.	°F.	Per ct.	Miles.	Per ct.	In.	Date.	°F.	°F.	°F.	°F.
Apr. 1	47	28	55	127	67	......	1	4	47	47	4
2	48	33	60	151	83	0.03	....	5	95	95	9
3	26	15	64	437	100	.02	....	......	121	95	9
4	28	17	64	250	20	......	....	......	149	95	9
5	40	22	52	222	50	......	....	......	189	95	9
6	47	29	54	137	13	......	6	4	236	142	13
7	53	33	53	354	7	......	7	10	289	195	23
8	73	36	32	514	53	.04	....	30	362	268	53
9	64	47	57	476	70	.20	....	21	426	332	74
10	39	30	72	365	93	.21	....	......	465	332	74
11	52	44	76	323	67	.61	....	9	517	384	83

Meteorological data for Huron, Dak., in 1887—Continued.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Positive temperature (T—43° F.).	Sum of daily temperature.		
									All.	All above 43° F.	All positive (temperature above 43° F.).
1887.	°F.	°F.	Per ct.	Miles.	Per ct.	In.	Date.	°F.	°F.	°F.	°F.
Apr. 12	54	43	72	60	67	------	--------	11	571	438	94
13	49	47	93	300	100	1.77	--------	6	620	487	100
14	41	37	89	265	67	.10	--------	------	661	487	100
15	38	30	75	369	100	.12	--------	------	699	487	100
16	43	35	75	58	100	------	--------	0	742	487	100
17	43	28	59	52	70	------	--------	0	785	487	100
18	44	25	50	85	0	------	18	1	829	531	101
19	45	26	53	109	33	------	19	2	874	576	103
20	47	27	54	158	10	------	--------	4	921	623	107
21	46	40	81	413	70	.56	--------	3	967	669	110
22	35	23	62	676	50	.10	--------	------	1,002	669	110
23	32	23	69	278	67	.03	23	------	1,034	669	110
24	34	25	68	222	80	.06	--------	------	1,068	669	110
25	41	23	51	147	0	------	25	------	1,109	669	110
26	45	33	64	144	17	.05	--------	2	1,154	714	112
27	56	38	55	329	93	.02	--------	13	1,210	770	125
28	58	33	44	306	33	------	--------	15	1,268	828	140
29	70	39	36	473	47	------	--------	27	1,338	898	167
30	73	46	41	358	20	------	--------	30	1,411	971	197
May 1	57	45	64	301	27	------	--------	14	1,468	1,028	211
2	39	31	73	634	80	.08	--------	------	1,507	1,028	211
3	53	26	42	235	3	Tr.	[a] 3	10	1,560	1,081	221
4	61	35	47	334	0	------	--------	18	1,621	1,142	239
5	63	34	43	254	17	------	--------	20	1,684	1,205	259
6	72	43	39	434	33	------	--------	29	1,756	1,277	288
7	75	49	44	657	33	------	--------	32	1,831	1,352	320
8	70	40	41	287	0	------	--------	27	1,901	1,422	347
9	72	44	43	214	0	------	--------	29	1,973	1,494	376
10	74	48	43	365	13	------	--------	31	2,047	1,568	407
11	71	51	52	351	23	------	--------	28	2,118	1,639	435
12	68	57	67	384	77	------	--------	25	2,186	1,707	460
13	65	55	76	359	93	.69	--------	22	2,251	1,772	482
14	57	39	56	314	27	------	--------	14	2,308	1,829	496
15	62	44	58	207	60	.01	--------	19	2,370	1,891	515
16	44	36	74	377	93	.04	--------	1	2,414	1,935	516
17	51	37	62	116	3	------	--------	8	2,465	1,986	524
18	63	45	56	367	0	------	--------	20	2,528	2,049	544
19	73	52	50	559	0	------	--------	30	2,601	2,122	574
20	75	57	55	470	37	------	--------	32	2,676	2,197	606
21	59	54	83	302	87	.48	--------	16	2,735	2,256	622
22	57	47	70	211	57	.03	--------	14	2,792	2,313	636
23	60	46	63	324	17	.02	--------	17	2,852	2,373	653
24	56	38	55	221	0	------	--------	13	2,908	2,429	666
25	62	40	52	79	3	------	--------	19	2,970	2,491	685
26	66	43	50	331	0	------	--------	23	3,0[illegible]	2,557	708
27	66	45	52	136	17	------	--------	23	3,102	2,623	731
28	61	53	76	208	33	.04	--------	18	3,163	2,684	749

[a] Light.

Meteorological data for Huron, Dak., in 1887—**Continued.**

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Positive temperature (T −43° F.).	Sum of daily temperatures.		
									All.	All above 43° F.	All positive (temperature above 43° F.).
1887.	° *F.*	° *F.*	*Per ct.*	*Miles.*	*Per ct.*	*In.*	*Date.*	° *F.*	° *F.*	° *F.*	° *F.*
May 29	63	39	46	421	40	Tr.	....	20	3,226	2,747	769
30	53	43	70	469	67	....	....	10	3,279	2,800	779
31	56	46	69	237	53	....	....	13	3,335	2,856	792
June 1	61	44	59	212	43	....	....	18	3,396	2,917	810
2	65	51	64	316	100	....	....	22	3,461	2,982	832
3	59	49	72	360	57	.43	....	16	3,520	3,041	848
4	56	40	60	190	0	....	....	13	3,576	3,097	861
5	70	54	60	371	0	....	....	27	3,646	3,167	888
6	83	59	47	441	7	....	....	40	3,729	3,250	928
7	70	62	77	234	67	.48	....	17	3,799	3,320	945
8	67	54	65	119	37	....	....	24	3,866	3,387	969
9	70	58	68	141	63	....	....	17	3,936	3,457	986
10	69	66	89	276	93	1.13	....	26	4,005	3,526	1,012
11	74	65	77	183	60	.17	....	31	4,079	3,600	1,043
12	72	61	72	160	20	Tr.	....	29	4,151	3,672	1,072
13	74	66	78	196	57	.03	....	31	4,225	3,746	1,103
14	80	67	66	340	7	....	....	37	4,305	3,826	1,140
15	81	69	68	461	0	....	....	38	4,386	3,907	1,178
16	77	56	52	301	20	....	....	34	4,463	3,984	1,212
17	75	49	45	280	0	....	....	32	4,538	4,059	1,244
18	73	59	63	211	23	.02	....	30	4,611	4,132	1,274
19	71	59	72	249	77	.47	....	28	4,682	4,203	1,302
20	65	50	62	336	67	.18	....	22	4,747	4,268	1,324
21	63	43	52	374	33	....	....	20	4,810	4,331	1,344
22	60	39	51	348	0	....	....	17	4,870	4,391	1,361
23	59	37	51	116	13	....	....	16	4,929	4,450	1,377
24	65	52	64	287	40	Tr.	....	22	4,994	4,515	1,399
25	69	54	62	423	7	....	....	26	5,063	4,584	1,425
26	73	62	70	603	53	....	....	30	5,136	4,657	1,455
27	77	64	67	438	90	Tr.	....	34	5,213	4,734	1,489
28	70	63	81	103	100	.92	....	27	5,283	4,804	1,516
29	73	60	67	290	80	.03	....	30	5,356	4,877	1,546
30	73	64	76	277	80	.12	....	30	5,429	4,950	1,576
July 1	72	59	67	131	53	1.38	....	29	5,501	5,022	1,605
2	63	58	84	214	93	.56	....	20	5,564	5,085	1,625
3	64	59	84	266	70	....	....	21	5,628	5,149	1,646
4	70	57	65	129	17	....	....	17	5,698	5,219	1,663
5	72	53	58	190	17	....	....	29	5,770	5,291	1,692
6	73	57	61	92	0	....	....	30	5,843	5,364	1,722
7	76	58	60	186	60	....	....	33	5,919	5,440	1,755
8	76	61	62	280	30	.03	....	33	5,995	5,516	1,788
9	71	51	56	119	0	....	....	28	6,066	5,587	1,816
10	82	56	43	424	33	....	....	39	6,148	5,669	1,855
11	68	61	80	304	70	....	....	25	6,216	5,737	1,880
12	70	55	64	101	0	Tr.	....	27	6,286	5,807	1,907
13	81	67	64	321	43	.03	....	38	6,367	5,888	1,945
14	86	61	48	502	17	....	....	43	6,453	5,974	1,988
15	80	65	62	324	43	....	....	37	6,533	6,054	2,025

Meteorological data for Huron, Dak., in 1887—Continued.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Positive temperature (T—43° F.).	Sum of daily temperature. All.	Sum of daily temperature. All above 43° F.	Sum of daily temperature. All positive (temperature above 43°F.).
1887.	°F.	°F.	Per ct.	Miles.	Per ct.	In.	Date.	°F.	°F.	°F.	°F.
July 16	69	58	69	276	93	------	--------	26	6,602	6,123	2,051
17	70	56	65	167	60	------	--------	17	a6,772	6,193	2,068
18	72	52	56	174	3	------	--------	19	6,844	6,265	2,087
19	67	61	81	163	80	------	--------	24	6,911	6,332	2,111
20	71	60	72	169	80	------	--------	28	6,982	6,403	2,139
21	67	53	66	166	27	------	--------	24	7,049	6,470	2,163
22	61	43	55	183	23	------	--------	18	7,110	6,531	2,181
23	67	57	63	294	57	1.09	--------	24	7,177	6,598	2,205
24	72	58	64	196	3	------	--------	29	7,249	6,670	2,234
25	78	63	65	477	70	.03	--------	35	7,327	6,748	2,269
26	73	60	69	276	43	------	--------	30	7,400	6,821	2,299
27	71	60	72	131	40	------	--------	28	7,471	6,892	2,327
28	74	65	74	283	40	------	--------	31	7,545	6,966	2,358
29	74	59	62	311	23	------	--------	31	7,619	7,040	2,389
30	69	57	59	124	3	------	--------	26	7,688	7,109	2,415
31	72	57	64	286	40	------	--------	29	7,760	7,181	2,444
Aug. 1	76	60	60	130	20	.01	--------	33	7,836	7,257	2,477
2	70	59	70	349	100	.32	--------	27	7,906	7,327	2,504
3	68	58	74	198	40	.15	--------	25	7,976	7,395	2,529
4	62	55	79	228	67	.04	--------	19	8,038	7,457	2,548
5	64	46	56	132	10	Tr.	--------	21	8,102	7,521	2,569
6	68	54	63	358	37	Tr.	--------	25	8,170	7,589	2,594
7	79	63	61	413	33	.19	--------	36	8,249	7,668	2,630
8	71	58	67	273	33	------	--------	28	8,320	7,739	2,658
9	66	58	79	257	93	.01	--------	23	8,386	7,805	2,681
10	72	64	76	231	43	.37	--------	29	8,458	7,877	2,710
11	68	51	60	121	13	------	--------	25	8,526	7,945	2,735
12	63	56	78	206	100	.48	--------	20	8,589	8,008	2,755
13	65	61	85	202	100	1.49	--------	22	8,654	8,073	2,777
14	70	60	71	107	30	------	--------	27	8,724	8,143	2,804
15	66	59	80	171	57	Tr.	--------	23	8,790	8,209	2,827
16	66	56	72	116	90	.10	--------	23	8,856	8,275	2,850
17	70	56	64	91	3	.05	--------	27	8,926	8,345	2,877
18	67	53	66	109	0	------	--------	24	8,993	8,412	2,901
19	69	58	70	185	3	------	--------	26	9,062	8,481	2,927
20	65	58	80	188	50	.47	--------	22	9,127	8,546	2,949
21	68	57	70	197	7	Tr.	--------	25	9,195	8,614	2,974
22	57	44	65	296	50	------	--------	14	9,252	8,671	2,988
23	51	41	71	146	37	Tr.	--------	8	9,303	8,722	2,996
24	53	40	65	78	60	Tr.	--------	10	9,356	8,775	3,006
25	52	44	76	99	83	.02	--------	9	9,408	8,827	3,015
26	55	45	72	139	100	------	--------	12	9,463	8,882	3,027
27	63	52	71	332	93	.06	--------	20	9,526	8,945	3,047
28	69	57	67	423	0	------	--------	26	9,595	9,014	3,073
29	64	59	86	381	67	.04	--------	21	9,659	9,078	3,094
30	67	63	88	248	50	.77	--------	24	9,726	9,145	3,118
31	67	64	92	196	73	1.20	--------	24	9,793	9,212	3,142

a On and after July 17 the numbers in the column "Sums of all temperatures" must be diminished by 100.

Meteorological data for Huron, Dak., in 1887—Continued.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Positive temperature (T—43° F.).	Sum of daily temperature.		
									All.	All above 43° F.	All positive (temperature above 43° F.).
1887.	°*F.*	°*F.*	*Per ct*	*Miles.*	*Per ct.*	*In.*	*Date.*	°*F.*	°*F.*	°*F.*	°*F.*
Sept. 1	68	61	80	119	90	Tr.	....	25	9,861	9,280	3,167
2	70	63	79	171	53	....	....	27	9,931	9,350	3,194
3	67	60	78	233	53	....	....	24	9,998	9,417	3,218
4	67	59	79	298	80	....	....	24	10,065	9,484	3,242
5	74	65	74	330	20	.04	....	31	10,139	9,558	3,273
6	68	55	67	289	3	Tr.	....	25	10,207	9,626	3,298
7	59	47	68	140	0	Tr.	....	16	10,266	9,685	3,314
8	73	57	60	440	43	....	....	30	10,339	9,758	3,344
9	52	39	63	360	0	....	....	9	10,391	9,810	3,353
10	50	46	86	159	83	.11	....	7	10,441	9,860	3,360
11	62	56	82	313	70	....	....	19	10,503	9,922	3,379
12	62	56	80	382	67	....	....	19	10,565	9,984	3,398
13	55	34	52	411	13	....	....	12	10,620	10,039	3,410
14	55	38	59	151	33	....	....	12	10,675	10,094	3,422
15	53	36	59	172	33	Tr.	....	10	10,728	10,147	3,432
16	63	45	53	586	3	....	....	20	10,791	10,210	3,452
17	64	52	66	359	67	Tr.	....	21	10,855	10,274	3,473
18	66	51	59	285	47	....	....	23	10,921	10,340	3,496
19	70	59	69	545	63	....	....	17	10,991	10,410	3,513
20	67	53	64	355	73	....	....	24	11,058	10,477	3,537
21	53	41	67	135	70	Tr.	....	10	11,111	10,530	3,547
22	46	36	71	225	47	....	....	3	11,157	10,576	3,550
23	45	28	55	230	43	Tr.	23	2	11,202	10,621	3,552
24	58	42	57	248	3	....	....	15	11,260	10,679	3,567
25	54	35	54	83	57	....	....	11	11,314	10,733	3,578
26	60	45	63	311	40	Tr.	....	17	11,374	10,793	3,595
27	49	41	73	365	67	....	....	6	11,423	10,842	3,601
28	49	33	58	61	0	....	....	6	11,472	10,891	3,607
29	53	38	62	74	0	....	....	10	11,525	10,944	3,617
30	53	39	66	158	3	....	....	10	11,578	10,997	3,627

MAIZE.

The record of the plantings and general condition of the corn for the season of 1888 is taken from the station Bulletin No. 9 by Prof. Luther Foster, director and agriculturist, and is as follows:

The corn experiment embraced a set of 39 plats, each containing 60 rows 24 hills in length. Thirty-three of these plats were planted with different varieties of corn, 18 of Dent and 15 of Flint, the rest being used for experiments in deep and shallow cultivation.

On the first 33 plats the planting began on the 7th and 8th days of May. Two rows of each plat were planted every day for thirty consecutive working days.

It may, perhaps, be unnecessary to state that these daily plantings were made with the object of determining the corn growing season, when germination begins, and the extreme length of planting time.

Preparation of soil.—The land used is a sandy loam, with a subsoil of clay, and slopes slightly to the northwest. It was plowed the previous August to a depth of 6 inches, and thoroughly harrowed in the spring just before planting. It had produced two crops of small grain, and had never been manured.

Planting.—The rows were made with a marker 3 feet 6 inches each way. Part of the corn was dropped by hand and covered with the hoe, the rest being put in with hand planters. Of the Dent corn, the hills contained 3 and 4 grains; of the Flint, 4 and 5.

The stand.—The early part of the season was not favorable for corn growing, being cold and wet. The coming up was quite irregular, from six to ten days frequently elapsing between the appearance of the first and last hills in a row. This was especially true of the first fifteen days' planting.

The stand in general was poor, resulting in part from unfavorable weather and bad seed, but principally from the work of ground squirrels. This latter evil was the most persistent and damaging one with which the corn experiment had to contend. The per cent taken depended upon location of the variety, whether more or less remote from the unbroken prairie. Notwithstanding all efforts to destroy the squirrels, the damage done was very great. For several successive days previous to planting poisoned corn was placed in every squirrel hole that could be found. This was done not only on the experiment ground, but also on the whole 80 acres and on the edges of the land immediately surrounding it. This work, reenforced with the trap and shotgun, was continued throughout the whole planting season.

Cultivation.—All the plats were given four different cultivations, a six-shovel corn plow and a double spring-tooth cultivator being used for the purpose. In addition to this they were twice hoed. Cultivation began on the 11th day of June and ended on the 17th day of July.

General remarks.—It was observed in all the plats that the earlier plantings grew larger and stronger than the after ones and that the silks and tassels made their appearance more regularly.

The ears of nearly all varieties of the Flint corn were infested with a species of worm. These did but little damage beyond marring the appearance of the ears. The Dents were not disturbed by the worms.

Immediately after the killing frost on the night of September 11 the corn on all the plats was cut and shocked. It was allowed to stand a few weeks before husking.

The results of a single season's work are only entitled to the public attention as showing the scope of the experiment undertaken.

Definite results of any practical value to the farmer can only be obtained by a continuance of the same experiment under a system of careful observations extending through a number of years. Of this a beginning has been made.

Tabulated statement.—In the following table that date of planting is taken which shows the least number of days from time of planting to maturity. The first seven to ten days planting came up and matured at the same time, while the coming up of the rest varied quite regularly with the time of planting.

The items in the columns headed "Up," "In tassel," "In silk,"

" Matured," and " Days to mature " apply only to the planting up to and including the date in the first column. The items in the other columns apply to the whole piece.

The per cent of corn standing and that taken by squirrels was made from actual daily counts of hills.

In computing the yield the corn was weighed instead of measured.[a]

Experiments of 1888 in planting corn at Brookings, S. Dak.

[First killing frost, 1888, September 12, a. m.]

Variety.	Date of planting.	Date of sprouting.	Date of tasseling.	Date of silking.	Date of maturing.	Days to mature.	Sums of positive (T−43° F.), planting to maturing.	Yield per acre of shelled corn.
Dents:							° *F.*	*Bush.*
White Rustler	May 14	June 5	July 20	July 30	Sept. 4	113	2,556	24¼
Austin's Calico	do	do	July 21	July 31	Sept. 10	119	2,692	27½
Dakota Yellow	May 13	June 4	July 18	do	do	120	2,696	24
Davis's White	May 14	June 6	July 23	July 30	Sept. 11	121	2,711	42
Hickory King	do	June 5	Aug. 16	Sept. 11		Silk.		
Chester County Mammoth	do	June 4	July 20	Aug. 11		Milk.		
Illinois Premium	do	June 5	Aug. 1	Aug. 10		Soft.		
Austin's Yellow	May 16	June 6	July 25	Aug. 1	Sept. 11	118	2,703	29
Davis's Yellow	do	do	July 21	do	Sept. 8	115	2,641	24
Edmund's Premium	do	June 8	July 25	Aug. 4		Soft.		31½
Pride of the North	do	June 4	July 18	July 27	Sept. 11	118	2,703	21⅛
Clearance Yellow	May 12	June 5	July 24	Aug. 10		Soft.		
Watson's Yellow	May 16	June 6	July 28	do		Fair.		
Improved Leaming	May 15	do	Aug. 1	do		Poor.		
Dakota Gold Coin	May 16	June 7	July 23	July 31	Sept. 6	113	2,601	27
Golden Beauty	May 15	do	Aug. 13	Aug. 22		Milk.		
Bloody Butcher	May 16	June 6	July 20	Aug. 4	Sept. 11	118	2,703	15
North Star	May 18	June 5	July 24	Aug. 1	Sept. 8	113	2,640	21⅛
Flints:								
Smut Nose	May 15	June 4	July 14	July 26	Aug. 20	107	2,187	37⅛
Compton's Early	May 14	June 6	July 17	July 31	Aug. 28	106	2,410	27
Top Over	May 12	do	July 19	Aug. 2	Sept. 2	113	2,527	28
Early Canada	May 17	do	July 23	do	Sept. 11	117	2,703	17
Self Husking	May 16	do	July 16	July 27	Sept. 2	109	2,505	45
Early Six Weeks	May 15	June 5	July 19	July 26	Aug. 19	96	2,162	15¼
Chadwick	May 17	June 7	July 16	do	Aug. 30	105	2,453	24⅛
Mandan Indian	do	do	July 11	July 18	Aug. 15	90	2,071	20
Longfellow	May 15	June 6	July 23	Aug. 2	Sept. 10	118	2,689	18
Minnesota White	May 16	do	do	do	Sept. 6	113	2,601	27¼
Mercer	do	do	July 16	July 26	Aug. 27	103	2,871	37
Waushakum	May 17	do	July 20	July 31	Sept. 11	117	2,703	36
Silver White	May 16	June 4	do	July 30	do	118	2,703	27
King Philip	do	June 8	July 26	Aug. 2	do	118	2,703	9⅛
Angel of Midnight	May 13	June 7	July 23	July 30	Sept. 1	111	2,504	34¼

[a] I regret not to be able to state the source whence the seed was obtained and the climatic peculiarities under which it was raised. According to Linsser's laws this must decide as to the behavior of the seed and plant in a new climate. I know, however, that some of the varieties had been raised in previous years in the neighborhood of Brookings, S. Dak.—C. A.

In comparing the maize experiments at Brookings with the climate of that region, I shall use the record of the Signal Service station at Huron, S. Dak. (lat. 44.3° N.; long. 98.1° W.; altitude above sea level, 1,300 feet), which is 70 miles west of Brookings, and the general meteorological tables for Huron as calculated for this agricultural usage are appended to this table of agricultural experiments.

Meteorological data for Huron, Dak., in 1888.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Temperature —43° F.	Sums of temperatures. All.	Sums of temperatures. Rejecting all below 43° F.	Sums of temperatures. All positive (temperature —43° F.).
1888.	° *F.*	° *F.*	*P. ct.*	*Miles.*	*P. ct.*	*In.*	*Date.*		° *F.*	° *F.*	° *F.*
Apr. 1	31	23	73	303	80	0.0	1	......	31	0	0
2	34	26	73	144	83	Tr.	....	......	65	0	0
3	44	34	68	97	3	.02	....	1	109	44	1
4	52	44	74	441	57	.50	....	9	161	96	10
5	37	26	66	287	33	.0	....	......	198	96	10
6	40	27	64	127	0	.0	6	......	238	96	10
7	46	29	58	210	13	.0	7	3	284	142	13
8	53	32	55	178	43	.0	....	10	337	195	23
9	45	39	81	312	67	.04	....	2	382	240	25
10	45	27	55	237	33	.0	10	2	427	285	27
11	35	17	52	273	7	.0	11	......	462	285	27
12	48	32	59	394	40	.0	....	5	510	333	32
13	52	36	57	275	0	.0	....	9	562	385	41
14	58	32	44	334	0	.0	....	15	620	443	56
15	47	33	63	260	3	.0	....	4	667	490	60
16	53	37	59	469	60	.0	....	10	720	543	70
17	39	21	55	473	13	.0	17	......	759	543	70
18	34	20	57	184	37	.0	....	......	793	543	70
19	34	19	58	188	0	.0	19	......	827	543	70
20	49	29	53	318	23	.0	20	6	876	592	76
21	59	35	48	154	70	.0	....	16	935	651	92
22	49	36	64	325	63	.0	....	6	984	700	98
23	44	28	56	179	60	.0	23	1	1,028	744	99
24	57	31	42	644	40	.0	....	14	1,085	801	113
25	56	39	55	698	63	.0	....	13	1,141	856	126
26	57	40	58	298	20	Tr.	....	14	1,198	913	140
27	42	39	87	364	100	.16	....	......	1,240	913	140
28	32	27	81	531	100	.16	....	......	1,272	913	140
29	34	27	73	300	100	.0	....	......	1,306	913	140
30	37	26	67	159	0	.0	30	......	1,343	913	140
May 1	40	35	81	385	100	.08	....	......	1,383	913	140
2	42	39	90	312	100	.44	....	......	1,425	913	140
3	40	35	84	409	100	.22	....	......	1,465	913	140
4	45	32	62	247	0	Tr.	4	2	1,510	958	142
5	51	34	56	209	70	.0	....	8	1,561	1,009	150
6	46	37	73	347	100	.34	....	3	1,607	1,055	153
7	48	37	70	259	70	.06	....	5	1,655	1,103	158
8	53	32	50	186	63	.0	....	10	1,708	1,156	168
9	57	31	45	195	67	.0	....	14	1,765	1,213	182

Meteorological data for Huron, Dak., in 1888—Continued.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Temperature —43° F.	Sums of temperatures. All.	Sums of temperatures. Rejecting all below 43° F.	Sums of temperatures. All positive (temperature —43° F.).
1888.	° F.	° F.	P. ct.	Miles.	P. ct.	In.	Date.		° F.	° F.	° F.
May 10	56	37	54	261	90	.42	--------	13	1,821	1,269	195
11	47	28	54	416	30	.0	--------	4	1,868	1,316	199
12	41	23	57	352	3	Tr.	12	-------	1,909	1,316	199
13	43	18	44	295	33	Tr.	13	-------	1,952	1,316	199
14	47	17	38	155	50	Tr.	14	4	1,999	1,363	203
15	46	30	57	331	47	.0	--------	3	2,047	1,409	206
16	48	29	55	105	50	Tr.	16	5	2,095	1,457	211
17	42	33	72	139	100	.12	--------	-------	2,137	1,457	211
18	44	32	65	155	37	.04	--------	1	2,181	1,501	212
19	52	43	73	430	73	.22	--------	9	2,233	1,553	221
20	63	51	66	317	63	.0	--------	20	2,296	1,616	241
21	58	50	76	288	100	.84	--------	15	2,354	1,674	256
22	55	48	78	400	100	.92	--------	12	2,409	1,729	268
23	52	44	77	391	100	.0	--------	9	2,461	1,781	277
24	53	45	74	207	67	Tr.	--------	10	2,514	1,834	287
25	58	44	63	79	23	Tr.	--------	15	2,572	1,892	302
26	54	49	83	244	100	.66	--------	11	2,626	1,946	313
27	59	44	62	375	77	.02	--------	16	2,685	2,005	329
28	57	40	56	290	33	.0	--------	14	2,742	2,062	343
29	55	40	59	156	53	.0	--------	12	2,797	2,117	355
30	55	43	65	216	50	.60	--------	12	2,852	2,172	367
31	54	39	63	109	47	Tr.	--------	11	2,906	2,226	378
June 1	51	36	60	206	0	Tr.	--------	8	2,957	2,277	386
2	57	43	62	130	7	Tr.	--------	14	3,014	2,291	400
3	66	53	64	439	67	.0	--------	23	3,080	2,314	423
4	64	53	67	573	77	.0	--------	21	3,144	2,335	444
5	50	41	72	378	70	.02	--------	7	3,194	2,342	451
6	55	43	66	166	50	Tr.	--------	12	3,249	2,354	463
7	73	61	68	541	20	.02	--------	30	3,322	2,384	493
8	69	60	76	496	67	.0	--------	26	3,391	2,410	519
9	54	49	83	508	100	.14	--------	11	3,445	2,521	530
10	63	48	62	234	17	.0	--------	20	3,508	2,541	550
11	61	55	82	176	70	.30	--------	18	3,569	2,559	568
12	70	56	63	182	40	.0	--------	27	3,639	2,586	595
13	75	63	69	228	37	.06	--------	32	3,714	2,618	627
14	74	59	65	153	27	Tr.	--------	31	3,788	2,649	658
15	80	70	75	382	40	.02	--------	37	3,868	2,686	695
16	81	70	71	393	8	.0	--------	38	3,949	2,724	733
17	79	65	65	180	23	.0	--------	36	4,028	2,760	769
18	78	65	68	355	0	.0	--------	35	4,106	2,795	801
19	74	67	78	465	40	Tr.	--------	31	4,180	2,826	832
20	68	56	68	523	73	.0	--------	25	4,248	2,851	857
21	59	48	66	615	57	Tr.	--------	16	4,307	2,867	873
22	61	44	54	528	90	.0	--------	18	4,368	2,885	891
23	61	45	57	436	93	.0	--------	18	4,429	2,903	909
24	62	52	71	299	90	.0	--------	19	4,491	2,922	928
25	62	51	70	108	87	.0	--------	19	4,553	2,941	947
26	57	54	90	389	100	.52	--------	14	4,610	2,955	961
27	62	55	81	104	97	.0	--------	19	4,672	2,974	980

Meteorological data for Huron, Dak., in 1888—Continued.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Temperature —43° F.	Sums of temperatures. All.	Sums of temperatures. Rejecting all below 43° F.	Sums of temperatures. All positive (temperature —43° F.).
1888.	°F.	°F.	P. ct.	Miles.	P. ct.	In.	Date.		°F.	°F.	°F.
June 28	65	59	84	376	53	.0	....	22	4,737	2,996	1,002
29	70	65	86	395	70	.02	....	27	4,807	3,023	1,029
30	82	73	76	346	57	.0	....	39	4,889	3,062	1,068
July 1[a]	80	....	....	282	....	.0	....	37	4,969	3,142	1,105
2	74	....	....	278	....	.0	....	31	5,043	3,216	1,136
3	66	....	....	150	....	.34	....	23	5,109	3,282	1,159
4	72	....	....	140	....	Tr.	....	29	5,181	3,354	1,188
5	76	....	....	208	....	Tr.	....	33	5,257	3,430	1,221
6	70	....	....	346	....	.26	....	27	5,327	3,500	1,248
7	70	....	....	230	....	.46	....	27	5,397	3,570	1,275
8	70	....	....	254	....	.02	....	27	5,467	3,640	1,302
9	66	....	....	122	....	Tr.	....	23	5,533	3,706	1,325
10	75	....	....	289	....	Tr.	....	32	5,608	3,781	1,357
11	82	....	....	285	....	Tr.	....	39	5,690	3,863	1,396
12	76	....	....	267	....	Tr.	....	33	5,766	3,939	1,429
13	67	....	....	234	....	.02	....	24	5,833	4,006	1,453
14	72	....	....	101	....	.02	....	29	5,905	4,078	1,482
15	68	....	....	357	....	Tr.	....	25	5,973	4,146	1,507
16	66	....	....	130	....	Tr.	....	23	6,039	4,212	1,530
17	69	....	....	328	....	.0	....	26	6,108	4,281	1,556
18	68	....	....	273	....	.0	....	25	6,176	4,349	1,581
19	69	....	....	127	....	Tr.	....	26	6,245	4,418	1,607
20	78	....	....	368	....	.0	....	35	6,323	4,496	1,642
21	77	....	....	263	....	.26	....	34	6,400	4,573	1,676
22	68	....	....	124	....	Tr.	....	25	6,468	4,641	1,701
23	70	....	....	197	....	.0	....	27	6,538	4,711	1,728
24	68	....	....	199	....	.01	....	25	6,606	4,779	1,753
25	74	....	....	167	....	.19	....	31	6,680	4,853	1,784
26	73	....	....	131	....	.07	....	30	6,753	4,926	1,814
27	78	....	....	185	....	Tr.	....	35	6,831	5,004	1,849
28	76	....	....	220	....	Tr.	....	33	6,907	5,080	1,882
29	77	....	....	227	....	.70	....	34	6,984	5,155	1,916
30	78	....	....	291	....	.0	....	35	7,062	5,233	1,951
31	65	....	....	254	....	.76	....	22	7,127	5,298	1,973
Aug. 1	70	....	....	229	....	Tr.	....	27	7,197	5,368	2,000
2	71	....	....	227	....	.01	....	28	7,268	5,439	2,028
3	74	....	....	95	....	Tr.	....	31	7,342	5,513	2,059
4	68	....	....	205	....	1.50	....	25	7,410	5,581	2,084
5	65	....	....	180	....	.48	....	22	7,475	5,646	2,106
6	64	....	....	181	....	.0	....	21	7,539	5,710	2,127
7	64	....	....	223	....	.01	....	21	7,603	5,774	2,148
8	55	....	....	404	....	.32	....	12	7,658	5,829	2,160
9	56	....	....	205	....	.16	....	13	7,714	5,885	2,173
10	56	....	....	200	....	.20	....	13	7,770	5,941	2,186
11	58	....	....	123	....	.0	....	15	7,828	5,999	2,201
12	59	....	....	140	....	Tr.	....	16	7,887	6,058	2,217

[a] Hours of observation changed July 15, from 7 a. m., 3 p. m., and 10 p. m. to 8 a. m. and 8 p. m. Mean D. P. and R. H. not known.

Meteorological data for Huron, Dak., in 1888—Continued.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Temperature —43° F.	Sums of temperatures. All.	Rejecting all below 43° F.	All positive (temperature —43° F.).
1888.	°F.	°F.	P. ct.	Miles.	P. ct.	In.	Date.		°F.	°F.	°F.
Aug. 13	68			407		Tr.		25	7,955	6,126	2,242
14	66			276		.28		23	8,021	6,192	2,265
15	60			69		.38		17	8,080	6,252	2,282
16	64			204		.10		21	8,144	6,316	2,303
17	64			74		Tr.		21	8,208	6,380	2,324
18	63			100		Tr.		20	8,271	6,443	2,344
19	67			84		Tr.		24	8,338	6,510	2,368
20	68			82		.02		25	8,406	6,578	2,393
21	66			185		Tr.		23	8,472	6,644	2,416
22	66			155		Tr.		23	8,538	6,710	2,439
23	71			305		.0		28	8,609	6,781	2,467
24	74			199		.0		31	8,683	6,855	2,498
25	71			129		Tr.		28	8,754	6,926	2,526
26	72			211		Tr.		29	8,826	6,998	2,555
27	70			235		Tr.		27	8,896	7,068	2,582
28	74			126		Tr.		31	8,970	7,142	2,613
29	72			147		.0		29	9,042	7,214	2,642
30	65			287		.0		22	9,107	7,279	2,664
31	54			146		.0		21	9,161	7,333	2,685
Sept. 1	61			159		.0		18	9,222	7,394	2,703
2	66			291		.0		23	9,288	7,460	2,726
3	63			259		Tr.		20	9,351	7,523	2,746
4	56			181		Tr.		13	9,407	7,579	2,759
5	68			501		.0		25	9,475	7,647	2,784
6	71			388		.01		28	9,546	7,718	2,812
7	64			209		.04		21	9,610	7,784	2,833
8	62			207		.0		19	9,672	7,846	2,852
9	63			293		.0		20	9,735	7,909	2,872
10	66			270		.0		23	9,801	7,975	2,895
11	52			286		.0		19	9,853	8,027	2,914
12	48			136		Tr.	12	5	9,901	8,075	2,919
13	65			531		.0		22	9,966	8,140	2,941
14	58			442		.06		15	10,024	8,198	2,956
15	52			308		.06		9	10,076	8,250	2,965
16	46			269		Tr.	16	3	10,122	8,296	2,968
17	47			153		Tr.	17	4	10,169	8,343	2,972
18	48			127		Tr.	18	5	10,217	8,491	2,977
19	60			291		Tr.		17	10,277	8,551	2,994
20	64			157		.02		21	10,341	8,615	3,015
21	61			100		Tr.		18	10,402	8,676	3,033
22	57			157		Tr.		14	10,459	8,733	3,047
23	60			256		Tr.		17	10,519	8,793	3,064
24	58			351		Tr.		15	10,577	8,851	3,079
25	50			224		Tr.	25	7	10,627	8,901	3,086
26	52			512		.0		9	10,679	8,953	3,095
27	43			228		.0		0	10,722	8,996	3,095
28	43			78		.0		0	10,765	9,039	3,095
29	45			153		Tr.	29	2	10,810	9,084	3,097
30	54			259		Tr.	30	11	10,864	9,138	3,108

Experiments in 1890 in planting corn at Brookings, S. Dak.

[Experiment Station Bulletin No. 24.]

Variety.	Dates of planting.	Dates matured.	Days to mature.	Yield per acre shelled corn.
Dents:				*Bushels.*
Loveland	May 17	Aug. 24	100	33.5
Hughson	do	Sept. 10	116	29.2
Davis White	do	(a)		32.4
Queen of the North	do	(a)		30.8
Dakota Dent	do	(a)		21.8
Dakota King	May 19	Sept. 12	116	33.6
Gold Coin	do	do	116	34.2
Flints:				
Squaw	May 17	Sept. 5	111	35.4
Pride of Dakota	do	do	111	26.2
Mandan Indian	May 23	Sept. 1	101	26.4
Hudson Bay	do	(a)		24.1
Mercer	June 3	Sept. 15	104	22.1
King Philip	May 17	Sept. 12	118	24.1
Compton's Early	May 23	Sept. 3	103	20.0
Early Six Weeks	do	do	103	24.3
Landreth's Extra Early	May 17	Sept. 12	118	32.6
Early Canada	May 23	do	112	30.5
Blue Blade	May 17	do	118	22.3
Smut Nose	do	Sept. 5	111	25.8
Self-Husking	May 23	Sept. 6	106	23.8
Chadwick	May 16	Sept. 1	108	25.3

[a] Some frosted.

NOTES.—First killing frost 1890, September 13, a. m.
The data for 1890 given in this table came to hand too late to allow of preparing the corresponding meteorological table.—C. A. June 30, 1891.

MAIZE.

INDIANA.

From experiments in planting maize, made at the Indiana Agricultural Experiment Station (see Agr. Sci., Vol. III, p. 192), the following results were deduced:

Planting on May 1 gave a loss at harvest of 5.47 bushels per acre; planting on May 21 gave a gain of 0.31 bushels per acre.

Deep plowing in 1886 and 1888 gave an increase over shallow plowing of 2.4 bushels per acre, and 0.1 bushel in 1888.

Deep culture with a cultivator of 3 to 4 inches gave better results than a shallow culture of from 2 to 3 inches.

As to rate of planting or density of stand, two kernels every 28 inches apart and three kernels every 36 inches apart seem to give the best results for hand planting. For machine planting, the best results were given with stalks 12 and 14 inches apart.

NEW YORK.

Prof. C. S. Plumb states, as the result of a research made by himself during the summer of 1886 at the New York Agricultural Experiment Station, on the growth of maize and its dependence upon climate, the following conclusions:

(1) That maize makes a positive daily growth upward from the appearance of the plant above ground till the plant has reached its maximum height.

(2) That the variation in the development of the plant from day to day and week to week is not controlled by meteorological conditions, for of two plants that one which is the most backward at the beginning of the season may eventually become the stronger, larger, and more vigorous of the two.

The measures on which these conclusions are based (see Agr. Sci., Vol. III, p. 1) were made day by day upon seven individual plants, and the averages are given in the following table; the date of planting was May 21, 1886, and the dates of sprouting extended from May 31 for plant No. 1 to June 4 for plant No. 7.

Date of observation.	Average height of 7 plants.	Sums for preceding 7 days.		Sunshine duration.	Rainfall.
		Air temperatures.	Soil temperatures.		
	Inches.	° *F.*	° *F.*	*Days.*	*Inches.*
June 6	3	452	517	28	0.76
June 13	8	475	572	60	.0
June 20	14	494	569	50	.0
June 27	23	466	553	46	.40
July 4	35	492	658	84	.0
July 11	41	523	597	50	.71
July 18	47	464	610	58	.73
July 25	61	472	602	50	4.93
Total		3,838	4,678	421	7.53

The unsteadiness of the growth is very notable. There was a steady increase up to July 4 and then a drop for fourteen days, but growing more rapidly during the last period. When the greatest growth was made in the eighth or last period, the total air and soil temperatures were less than in the fifth period, when great growth was also made. During this last period of greatest growth the rainfall was large, while during the previous period of great growth the rainfall was zero. Evidently it needs a peculiar combination of rainfall, temperature, and sunshine to bring about the rapid growth. According to Frear, the very rapid growth of plants observed immediately after rainfall is largely due to a simple expansion of the cells with water.

Although a soil gains some nitrogen from the air as brought down

by the rain water, yet it loses a large quantity by the drainage water, which is, of course, richer in nitrogen than the rain. In 1886 and 1887 Berthelot determined by measurement that the nitrogen carried from the soil by drainage water is nearly ten times that brought to the soil by rain water. It is therefore economical to return this drainage water to the field, as far as possible, and thus return with it the nitrogen which has at great expense been given, in the shape of fertilizers, to the field by the farmer. (Agr. Sci., Vol. III, p. 35.)

MISSOURI.

Dr. P. Schweitzer, of the Missouri Agricultural Experiment Station, publishes in Bulletin No. IX an elaborate study of the chemical changes that go on in the various parts of the maize plant at different stages of growth. The plant takes up nearly all the ash ingredients during the first stages of growth. The more ash constituents a plant takes up over and above its needs the quicker is its development finished and the smaller is the crop. The young plant takes up nitrogen with extraordinary avidity, and contains a considerable quantity of it. The crop of corn from an acre of land removes therefrom 219 pounds of ash and 135 pounds of nitrogen. The ears in this crop alone contain 52 pounds of ash and 86 pounds of nitrogen. (Agr. Sci., Vol. IV, p. 84.)

PENNSYLVANIA.

The relation between meteorological conditions and the development of corn is elaborately presented by Messrs. Frear and Caldwell in the annual report for 1888 of the Pennsylvania State College Agricultural Experiment Station, at Harrisburg, Pa. By testing samples of corn at various stages of its growth we obtain not only some idea of the nature of the changes going on in the plant under the influence of the climate and soil, but the records of past seasons on a given variety at a given locality should give us the means of approximately estimating what will be the crop of the present year. For instance, the loss or gain of dry matter is shown in the following table for one variety of corn out of many that were tested at the Pennsylvania Station.

Dry weight in 1 acre of several varieties of corn at different stages of growth.

Variety.	Fully tasseled.	Ears filling out.	Kernels begin to glaze.	Mature ears.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Blount's Prolific	2,735	5,289	4,695	2,310
Chester Mammoth	3,392	4,337	5,690	3,073
Golden Beauty	2,499	3,950	4,619	2,835
Do	2,845	3,443	4,636	3,077
Golden Dent	2,633	3,825	5,344	2,529

Such tables as these show that the weight of the mature ears at harvest will not differ much from the weight of the whole plant when dried at the stage of full tasseling, the variations from this rule being about 10 per cent above or below for these varieties.

ILLINOIS.

The closeness with which corn or maize or other cereals may be planted depends not only upon the quantity of moisture available in the soil, but also upon the ultimate proposed nature of the crop. Thus in experiments made by the Illinois Agricultural Experiment Station, when corn is planted for ensilage one plant to every 3 inches gave the best result. When planting for the grain the thinnest planted plats gave 5,664 and the thickest planted gave 18,932 ears per acre. As to the date of planting, May 4 to May 19 gave the best harvest.

As to mode of planting, hills nor drills nor fertilizers gave any strongly marked differences.

As to pruning the roots, the pruned and unpruned showed no special difference in regard to size, vigor, date, or yield of harvest. (Agr. Sci., Vol. II, p. 162.)

The development of corn from week to week during the growing season has been studied by Thomas F. Hunt at the University of Illinois Agricultural Experiment Station, at Champaign. He states that the same 18 varieties of corn have been grown at this institution during each of the years 1887, 1888, and 1889, the same varieties being always grown on the same plats and the seed obtained from the same source. The average yield of air-dried corn per acre for the 18 varieties was 29.4 bushels in 1887, 83.2 bushels in 1888, and 66 bushels in 1889. Meteorological conditions appear to have been largely, if not solely, the causes of these differences in the yield. In 1889 measures were made weekly on three plants on each hill of Edmund's Golden Dent, which is usually an early variety, but this year matured late, owing to the low temperature. The corn was planted four kernels to a hill on the 4th of May; it sprouted on the 20th of May, the soil having been very dry, and made slow growth to June 10, on account of the low temperature. The following table shows the weight of dried substance in a hill of three plants of uniform character:

Date of cutting.	Average weight.	Remarks.
	Grams.	
June 10	0.51	
June 17	2.48	
June 25	10.11	
July 1	33.84	
July 8	75.46	
July 15	197.99	
July 22	322.91	Tassels showing; not in bloom; no silk.
July 30	408.07	All in tassel; in bloom; in silk.
August 5	589.10	
August 12	681.55	Silks dead or partly so.
August 19	724.449	Soft milk stage.
August 26	949.53	Milk stage or passed.
September 2	906.22	Mostly glazed.
September 10	1,034.55	Varies from milk stage to ripe.
September 16	1,176.00	All ripe except 1 ear.

Professor Hunt finds that the varieties of corn that mature about September 25 give the largest yields; date of planting has little influence on the yield. Depth of planting and drilling versus hill planting did not affect the yield in 1888 or 1889. The quantity of seed planted was more important than the allotment of the kernels to the hills; preventing the growth of weeds was more important than stirring the soil; pruning of roots injured the crops; shallow-working cultivators gave better results than deep-working; commercial fertilizers did not materially increase the yield, but stable manures did so. (Agr. Sci., Vol. IV, p. 184.)

MAIZE AND PEAS.

NEW YORK.

Sturtevant (1884) gives the results of two years' observations (1883 and 1884) at the experiment station, Geneva, N. Y., on the thermal constants of many varieties of maize and peas. He observed both the temperature of the soil and the air, and takes for his computations always the first plant which sprouted, bloomed, or ripened. Observations of 128 varieties of maize, four hills to each variety, gave an extreme variation of 19 days between the blooming of the first and last hill, the average interval being 4.92 days. As Sachs adopts 49.1° F. as the lowest temperature at which maize will germinate, and Köppen gives 49.2° F., therefore Sturtevant adopts 50° F., and considers that any observed temperature, less 50° F., leaves a remainder that is nearly proportional to the growth of maize at that temperature. A similar lower limit of 44° F. is adopted for the growth of the pea. He notes that in 1885, by trial at this experiment station, the "Chester County Mammoth Corn" germinated

in 430 hours at a temperature which was between 37° and 42°. averaging above 40° F., while the Waushakum variety required 460 hours at the same temperature.

Sturtevant calculates the sum total of temperatures by three methods, a comparison of which is instructive. His results are in the following table:

Thermal constants for maize at Geneva, N. Y., from germination to blooming.

Variety and subvariety.	Sums of all mean daily air temperatures.	Sums of all positive mean daily air temperatures, less 50° F.	Sums of all positive daily means of temperature of air, and soil at 1 foot depth, less 50° F.
Sweet corn:	° *F.*	° *F.*	° *F.*
Crosby's Early	3,595	845	937
Daily Dutton	3,181	756	859
Egyptian	4,342	1,042	1,132
Stowell's Evergreen	4,400	1,050	1,147
Flint corn:			
Forty Days	3,328	803	854
King Philip	3,751	901	965
Rural Thoroughbred	4,668	1,118	1,210
Waushakum	3,693	893	956
Dent corn:			
Adams Early	3,589	839	978
Benton	4,187	1,012	1,066
Blount's Prolific	4,737	1,162	1,235
Chester County Mammoth	5,192	1,342	1,319
Sibley's Pride of the North	3,818	943	987

The dates were: Corn planted May 16, 1883, and May 19, 1884; sprouted May 28, 1883, and May 26, 1884; bloomed July 16 to August 8, 1883, and July 16 to August 26, 1884.

Thermal constants for peas from sprouting to maturity at Geneva, N. Y.

Variety.	Sums of all mean daily air temperatures.	Sums of all positive mean daily air temperatures, less 44° F.	Sums of all positive means of air and soil temperatures at 1 foot depth, less 44° F.
	° *F.*	° *F.*	° *F.*
American Wonder	3,516	1,150	1,236
Champion of England	4,516	1,377	1,506
Kentish Invicta	3,674	1,176	1,501
McLean's Advance	4,515	1,376	1,520
Premium Gem	3,836	1,152	1,250
Telephone	4,576	1,408	1,524

Peas planted April 21 and May 12, 1883; April 28, 1884; ripened July 10 to August 6, 1883; July 2 to 28, 1884.

These figures show eccentricities from year to year in the same variety, but the peculiarities of the varieties are much larger than these eccentricities. Sturtevant suggests that actinism has an influence scarcely second to temperature.

SORGHUM.

UNITED STATES.

W. E. Stone (Agr. Sci., Vol. IV, p. 166) summarizes the results of the experiments on sorghum published by Wiley in Bulletins Nos. 20 and 26, Division of Chemistry, United States Department of Agriculture. He says the controlling conditions of success are suitable soil and climate, proximity of cane fields to the factory, supply of water and fuel, cost of the factory, and careful control of its operations. All experience points to southern central Kansas as the region best adapted to the growth of the sorghum. In New Jersey the plant, which at one time gave hopeful results, has deteriorated until it has become a worthless variety for sugar making, or even for the production of sirup. In Louisiana the results were disappointing in seasons which were the most favorable for the sugar cane. At Conway Springs, Kans., the average percentage of cane sugar was 12.42 in 1888 and 11.98 in 1889, being the best record of all.

In general, with a normal amount of moisture, and other things being equal, the percentage of sugar depends upon the amount of sunshine received; excessive moisture is detrimental, as it directly interferes with nutrition and indirectly as being accompanied by cloudiness.

A mean temperature of 70° F. is the minimum necessary to mature early varieties. The semiarid region south of the isotherm of 70° F. in the southwest central portion of the United States is best adapted to the growth of sorghum. East of the Mississippi the recurrence of wet seasons renders the crop uncertain. A permanently improved plant can certainly be developed from existing varieties by selection.

OATS.

KANSAS.

During the drought of 1890 the Kansas Agricultural Experiment Station secured the following comparative observations: On unplowed land the yield of listed oats was 2.4 bushels per acre better than on plowed land; the yield of drilled oats was 1 bushel per acre better on unplowed land; the yield of oats cultivated into the soil was 5 bushels per acre better on the unplowed land; the oats sown broadcast on plowed land gave the same results as the oats cultivated into unplowed land; the oats plowed under gave the least harvest of

all the five methods of seeding, while the drilled oats gave the best. This superiority of the drilled oats is probably due to the fact that the instrument pressing firmly upon the soil makes a firm bed at the bottom of the drill, into which the seed is dropped. In a loose soil oats run to straw, but in a firm soil they give a larger percentage of grain. In the present case oats drilled into unplowed land gave 34.5 bushels per acre, but when plowed under gave 21.6 bushels, or a loss of 35 per cent.

As to the time of harvesting oats, they should be cut early, viz, in the dough stage, if the straw is wanted for feed; but if the grain alone is wanted they should be allowed to mature, notwithstanding the fact that there is then a greater loss due to the beating out or dropping of the grain in harvesting. (Agr. Dept. Exp. Sta. Record, Vol. II, p. 222.)

OHIO.

In Bulletin No. 3 of Volume III of the Ohio Agricultural Experiment Station it is shown that the experiments of 1889 indicate that more cultivation should be given in dry seasons than in wet seasons.

FREEZING OF PLANTS AND SEEDS.

Detmer (1887), with reference to the effect of low temperatures on plants, finds:

(1) Fruits and seeds that have been dried in the air can be exposed for a long time without injury to very low temperatures, but if they have first been swollen with moisture they are destroyed by low temperatures. In the case of wheat exposed to a temperature of —10° C., although it will germinate, still its power of growth is decidedly less than before.

(2) Many plants and parts of plants withstand temperatures below freezing, and many bacteria withstand much lower temperatures; those experimented on by him were not killed by an exposure to temperatures of —17° C.

(3) In accordance with Sach's experiments, he finds many plants which after being frozen survive if they are thawed out in water at low temperatures (6° C.), but not when thawed out in water at +17° C., thus showing the manner in which a warm rain may act injuriously upon a forest.

(4) Certain plants are definitely destroyed by freezing independently of the subsequent thawing, such as the leaves of the begonia.

(5) Experiments have given a negative result as to the question whether any plant, although accustomed to the warmest climate, can be killed by a short exposure to a low temperature which is, however, still above freezing. (See Wollny, X, p. 236.)

WHEAT.

A detailed study of the relation of low temperatures to the growing of wheat has been made by S. G. Wright, of Indiana, from which I take the following conclusions:

Sleet.—When the winter wheat has its blades covered with ice that has fallen as sleet, and after the ice has melted off a microscopic examination shows the cellular structure to be altered, the epidermis is separated from the underlying cells and there is a general disunion of the cells, and when the growing season comes the plants are found to be entirely dead.

Sudden thawing.—Wheat plants exposed to a very low freezing temperature in dry air if thawed out slowly are not much injured, but if thawed out rapidly the younger sprouts are completely killed and the older ones subsequently die. The similar rule obtains for the germination of seeds. When frozen seeds were quickly thawed out only 18 per cent germinated, but when slowly thawed out 86 per cent germinated.

Freezing temperature of the juices of the wheat.—The juice extracted by pressure from the wheat has a lower freezing point than that of pure water when contained in its original living tissues, but after being extracted by pressure it freezes at an intermediate point below that of pure water. Again, the juice extracted from plants that have been exposed to a low winter temperature withstands freezing better than the juice from plants that have not had such exposure. For example, the juice within the cells was not frozen at —13° C., while that thrust out of the cells froze at —6° C., and in general the power to resist freezing is increased by exposing plants to the ordinary winter temperatures of the open air.

Method of sowing.—The best method of sowing wheat in order that it may withstand severe winter weather is (1) to avoid mulching or having any layer of porous material about the roots of the wheat, as experiment shows that this is a decided injury both to the wintering, the after growth, and the harvest. An average depth of seed planting of 1.5 inches is much better than three-fourths inch or 3 inches.

Range of temperature for germination.—According to Sachs, the minimum temperature is 5° C. and the maximum 37° or 38° C. According to Haberlandt, the temperature for germination ranges between 0° and —4.8° C. at the lower limit and 31° to 37° C. at the upper limit. Wright's experiments, at a constant temperature of 39° C., gave germination successful in forty-eight hours; at a temperature of 42.5° C. only a very few seeds could be made to germinate. At a temperature of 0° C. the seeds germinated in ten days; hence the extreme range of germinating temperatures for winter wheat of the varieties thus tested in Indiana is from 0° to 42.5° C. As to the effect

on germination of freezing the seeds just before they were ready to germinate, it was found that seeds soaked until ready to germinate and then kept frozen for a length of time required a longer time to complete the germination than did those that had not been frozen; the retardation increased in proportion to the duration of the freezing, amounting to about twelve days for a freezing of twenty-four days. The percentage of thawed-out seeds that germinated was also smaller in proportion as the duration of the freezing increased, being 44 per cent for a duration of twenty-four days.

Changes in the seeds produced by frost.—After the seeds had remained frozen for ten to twelve days a white, glutinous material oozed out at every slight break in the coat of the seed. A microscopic examination showed that the cell wall and starchy protoplasm was almost entirely disorganized, but the starch granules themselves were entirely unaffected. Strange to say, the power of the seeds to germinate was not destroyed by this. (Agr. Sci., Vol. IV, p. 337.)

Protection from frosts.—The formation of artificial clouds of smoke for the protection of plants from frost is generally successful, and should be resorted to in critical cases; thus, in a vineyard at Pagny about 3 a. m. of May 13, 1887, when the temperature was 3° F. below freezing, liquid tar was ignited, which had been poured into tin boxes, as also pieces of solid tar. Large clouds of smoke quickly enveloped the vineyard; the fires lasted for about two hours, but the smoke lasted considerably longer. All injury to the plants by frost was entirely prevented. (Agr. Sci., Vol. I, p. 172.)

INJURIES AND BENEFITS DUE TO WIND-BREAKS.

Protection against the injurious effects of wind may be obtained by the use of wind-breaks, which are usually made by planting a couple of rows of trees on the windward side of the field, or by so arranging the plantation that the hardiest and most vigorous deciduous trees are on the windward side. According to Bulletin No. IX issued by the Cornell University Agricultural Experiment Station, the benefits derived from wind-breaks are the following: Protection from cold, diminution of evaporation from soil and plants, diminution of the number of windfalls, diminution of liability to mechanical injury to trees, retention of snow and leaves, facilitation of outdoor labor, protection of blossoms from severe winds, protection of trees from deformity of shape, diminution of evaporation and drying up of small fruits, diminution of the encroachment of sand or the loss of dry soil or the scattering of rubbish, increased rapidity of maturity of fruits, and encouragement of birds that are beneficial to agriculture.

Among the organisms arrested by wind-breaks and usually reckoned as an injurious climatic influence are the fungi or the spores of fungi.

Jensen has, however, shown that bunt in wheat and smut in oats or barley or rye can be almost wholly prevented by washing the seed before sowing, in water whose temperature is not lower than 130° F. nor higher than 135° F. The sacks to receive the seeds should also be disinfected. Professor Kellerman shows that if the seeds are previously soaked in cold water for eight hours the hot-water wash may have a temperature of 124° to 128°. I infer that the spores of the smut, having been by the winds blown over the field in the ripening period, have stuck to the grains from that time on to the next sowing season. (Agr. Sci., Vol. IV, p. 100.)

THUNDERSTORMS AND OZONE.

A. L. Treadwell seems to have shown that the souring of milk during thunderstorms can not be attributed to any formation of ozone, and is more likely to be due to the fact that the bacteria causing this souring multiply with unusual rapidity during the warm sultry weather that precedes and accompanies thunderstorms. (Agr. Sci., Vol. V, p. 108.)

PRUNING VERSUS CLIMATE.

Kraus (1886) in some experiments on pruning hop vines shows first that those that were not pruned had an advantage in the early growth, especially in the cold and wet of June, 1886, in Germany, but in consequence of this precocity the early ones suffered from frost. Those that were early pruned surpassed them in the harvest.

Those that were pruned late gave the smallest harvest, but of the highest quality, the leaves remaining a beautiful green up to the harvest time, while those that were not pruned or those that were late pruned turned dark and soon yellowed.

This explains why for a long time it has been impossible to define exactly the climate that is best for the cultivation of hops, since it is now evident that changes in the pruning, harmonizing with peculiarities of weather or locality, have so great an influence upon the successful cultivation. (See Wollny, X, p. 236.)

WHEAT, TEMPERATURE, AND RAIN IN ENGLAND.

The wheat harvest of England has been studied by an anonymous writer. (Nature, 1891, vol. 43, p. 569.) I do not know the authorities for his statements as to the character of the harvests from year to year, but reproduce in the following tables the figures given by him as to the general character of the wheat harvests for each year and the corresponding mean temperatures and total rainfall for the months of June, July, and August as observed at the Royal Observatory, at Greenwich. Certain deductions are given by him as to the connection between the harvests and these items of the weather, but a more careful study of the figures convinces me that taken as they stand no infer-

ence can be safely drawn from them which will endure the test of critical examination. Any small selection of years may be made which will seem to support some suggested relation between temperature, rainfall, and crop, but other years will be found to contradict this. In a general way good crops result from hot and dry summers and bad harvests depend upon the large rainfalls rather than on the low temperatures. I have added the column of departures and have computed the probable errors of the averages, the study of which shows that the temperatures of the good harvest seasons are not sufficiently above those of the poor harvest seasons to justify the conclusion that warm seasons are intimately connected with good harvests. If, however, we go into more detail and examine all of the fifty-three years from 1816 to 1888, inclusive, and arrange them by the character of the harvests, we find innumerable contradictions. The study of the rainfall with its probable errors, or rather its probable variability, shows a somewhat stronger argument in favor of the idea that large rainfalls accompany poor harvests, and yet here again the contradictions are too numerous to allow us to suppose that this simple statement expresses exactly any law of nature. Thus the largest rainfall of 1888 and the small rainfall of 1886 both contradict this law. In the notes a few statements are made by the author as to special occurrences which seem to him to explain these anomalous cases, and by hunting through the records a few more notes might have been added so that after leaving out the anomalous cases one might say that the remainder accords well with the idea that dry hot summers give large crops and that heavy rains give poor crops. In general, however, it seems more proper to conclude that we are far from having attained the expression or formula connecting the crops and the weather, and that even if we knew this it would be improper to study the crops of England with reference to the temperature and rainfall at Greenwich, or, indeed, any other single station.

English wheat harvests and Greenwich weather.

[Weather in June, July, and August.]

I. SUPERIOR WHEAT HARVESTS.

Year.	Character of harvest.	Temperature.		Rainfall.	
		Observed.	Dep.	Observed.	Dep.
		° *F.*	° *F.*	*Inches.*	
1775	Plentiful	62.0	+0.8	(?)	....
1779	....do	62.3	+1.1	(?)	....
1791	Abundant	59.5	−1.7	Dry.	....
1818	Most abundant	64.3	+3.1	1.4	−4.3
1819	Fine	60.3	−1.9	4.6	−1.1
1820	Productive	58.0	−3.2	8.2	+2.5
1825	Early and good	62.0	+0.8	3.3	−2.4
1826	Remarkably early and very great	64.0	+2.8	5.1	−0.6
1827	Good	60.0	−1.2	2.9	−2.8

English wheat harvests and Greenwich weather—Continued.

I. SUPERIOR WHEAT HARVESTS—Continued.

Year.	Character of harvest.	Temperature.		Rainfall.	
		Observed.	Dep.	Observed.	Dep.
		° *F.*	° *F.*	*Inches.*	
1833[a]	Abundant	59.4	−1.8	6.7	+1.0
1834[b]	Early; very productive	62.5	+1.3	11.3	+5.6
1835	Good	62.6	+1.4	4.5	−1.2
1840	Fine yield	59.8	−1.4	3.9	−1.8
1849	Above the average	61.0	−0.2	3.8	−1.9
1851	....do	61.0	−0.2	7.2	+1.5
1854	Extremely good	59.0	−2.2	5.6	−0.1
1857	Above the average	63.9	+2.7	6.0	+0.3
1858	....do	62.5	+1.3	5.7	0.0
1863	Abundant	60.3	−0.9	6.6	+0.9
1864	Good	59.6	−1.6	2.5	−3.2
1868	Productive	64.4	+3.2	4.1	−1.6
1874	Very good	60.9	−0.3	6.4	+0.7
1888[c]	Above the average	58.4	−2.8	13.8	+8.1
	Mean of 23 and 20, respectively	61.2		5.68	
	Probable errors of these means	±0.37		±0.65	

II. INFERIOR WHEAT HARVESTS.

Year.	Character of harvest.	Temperature Observed.	Temperature Dep.	Rainfall Observed.	Rainfall Dep.
1789	Very deficient	59.7	+0.3	Wet.	....
1792	Inferior	58.3	−1.1	Wet.	....
1795	Very defective	57.8	−1.6	(?)	....
1800	Bad	60.7	+1.3	Wet.	....
1810	Scanty	60.0	+0.6	(?)	....
1811	Very scanty	59.0	−0.4	(?)	....
1812	Very defective	56.0	−3.4	(?)	....
1816	Very great deficiency	55.2	−4.2	8.4	−0.2
1817	Deficient	57.4	−2.0	7.9	−0.7
1821	Inferior	57.8	−1.6	7.0	−1.6
1823	Deficient	57.8	−1.6	7.1	−1.5
1828	Bad	60.3	+0.9	12.0	+3.4
1829	Inferior	59.0	−0.4	9.4	+0.8
1838	Late; unproductive	59.1	−0.3	7.3	−1.3
1839	Damaged	59.3	−0.1	7.6	−1.0
1848	Very bad	59.5	+0.1	10.6	+2.0
1852	Below the average	61.7	+2.3	11.4	+2.8
1853	Bad	60.1	+0.7	11.0	+2.4
1860	Very deficient	56.7	−2.7	11.6	+3.0
1867	Deficient	59.8	+0.4	10.2	+1.6
1873[d]	Very deficient	61.7	+2.3	7.6	−1.0
1875	Very unsatisfactory	60.3	+0.9	9.8	+1.2
1876[e]	Unsatisfactory	62.7	+3.3	3.7	−4.9
1877[e]	....do	62.0	+2.6	6.0	−2.6
1879	Worst known	58.5	−0.9	13.3	+4.7
1880	Deficient	60.6	+1.2	7.1	−1.5
1881	....do	61.1	+1.7	7.9	−0.7
1886[f]	....do	61.0	+1.6	4.1	−4.5
	Mean of 28 and of 21, respectively	59.4		8.6	
	Probable errors of the means	±0.33		±0.54	

[a] May was very dry.
[b] The winter was very mild; the spring very dry.
[c] The winter and early spring were very cold; May was very dry, with much sunshine.
[d] Frost occurred at blooming time.
[e] The spring was cold.
[f] The winter and early spring were very cold; May was very wet.

SUGAR CROP AND RAIN IN BARBADOS.

Sir R. W. Rawson, as governor of the British colonies at Barbados, published (1874) a colonial report, printed by the house of assembly, giving an elaborate study of the dependence of the cane-sugar crop upon the monthly and annual rainfall. Barbados offers an exceptional opportunity for such study, since the cane is the only staple and is nearly all exported, so that the records of the crop are accessible in the customs' returns. Moreover, the number of rainfall records averaged more than 1 to a square mile, being 178 for the whole island and for a period of about twenty-five years, this remarkable system of observations being due largely to the labors of Dr. R. Bowie Walcott, who still resides in the parish of St. Joseph, and was, in May, 1890, on the occasion of my recent visit to him, still active in collecting rainfall data. To his devotion and Governor Rawson's assistance we owe this unique study of rainfall and sugar crop. It is impossible for me at present to do more than give the accompanying Tables I, II, and III of monthly rainfalls and annual crops. The crops, as given in Tables II and III, in hogsheads, are credited to the years in which they passed through the custom-house. The cane is usually gathered and the sugar and molasses shipped between January and May; after the latter date the fields are newly planted and in eighteen months are again ready for cutting, so that the crop of any year has been grown under the influence of the rain of the preceding year and the latter half of the year preceding that. In the second table I give the dates of the first shipment of sugar each year, thus showing whether the crop was gathered early or late, and also the general character of the crop as credited to that year.

Table III illustrates Governor Rawson's conclusion that the crop of any year is influenced only in a slight degree by the rainfall of that year, but depends upon the rainfall of the preceding year. Thus it is arranged according to the quantity of rainfall, and the crop of the following year is compared with the rain of the current year; the wet years are followed by large crops the next year, while the dry years are followed by small crops; the increase being 10 per cent after a wet year and the decrease being 12 per cent after a dry year.

The general development of the sugar plant is illustrated in the following extract (see p. 33, Rawson's Report):

The influence of the rainfall in particular months and seasons upon the coming crop is generally felt and admitted, but not known with any certainty. It is believed, writes an experienced agriculturist, that any marked excess of rain during the first six months of the year is injurious both to the crop that is being reaped and to that which is to follow. The cane plant during the early stages of its growth is very hardy and requires but little moisture; the small

early shoots are hard and fibrous, and very different from the large succulent shoots which are afterwards produced and which lengthen into the juicy reed whence the crop is made. In ordinary and favorable years, with light showers during the first six months, the young canes make no marked progress, but the roots are increasing in length and strength, and in the months of July and August the plant begins to sucker, as it is called, and to put out the shoots which form the canes, but these make no great progress in length before the end of August and in September and October, when the rains usually come to their aid at the critical time. They then grow with extreme rapidity, are extremely tender and succulent, and a short spell of dry weather at that time usually does serious mischief. If, however, the first six months of the year are wet, and the young canes are excited to an abnormal rapidity of growth, they are liable to be seriously affected by any interval of dry weather in the middle of the year. Moreover, rainy weather in the reaping season retards the manufacture, and, especially in the black soils which contain an excess of iron variously combined, causes a great loss from the rotting of the canes at the roots.

An illustration of this is afforded by the rainfall and crops of 1860 and the two following years. 1860 was a model year; the rain fell at the right time, and in exactly the average quantity, 57.91 inches, of which 12.46 fell during the first six months. The crop of 1861 would undoubtedly have reached 55,000 hogsheads but for the wet reaping season of that year, in which the rainfall of the first six months was 31.93 inches—6.35 in April, 8.01 in May, and 8.01 in June. The consequence was that the crop only reached 49,745 hogsheads, and although so much rain fell throughout the year (73.82 inches), the following crop of 1862 was only 46,120 hogsheads.

In the same manner the heavy rainfall of 1855 (77.31 inches, of which 30.68 fell in the first six months) was followed in 1856 by only a moderate crop (43,077 hogsheads), although the reaping season of that year was most favorable. The result, however, is by no means constant.

The sugar-crop records go back to the year 1806, but the returns are only interesting since 1847, which was the first in which the crop recovered from the effects of emancipation in 1839. Since 1847 there has been a steady increase until the crop has attained nearly twice what it was before emancipation. There has also been a slow increase in acreage of canebrake; the size of the hogsheads has been gradually increasing since 1806; there has been a decided increase in the usage of guanos and other foreign manures; there has also been a very decided improvement in the machinery and processes for crushing the cane and manufacturing the sugar.[a]

[a] Although Governor Rawson was evidently conscious of these progressive changes, and in fact, mentions most of them, yet he does not approximately eliminate their effects by taking the difference between the individual crops and a progressively increasing ideal normal, but takes the difference between the simple average and the individual years; his results, therefore, need to be computed and all the data for this purpose are given in the tables herewith.—C. A.

The average crop divided by the average rainfall of the preceding year shows that each inch of rain corresponds to about 800 hogsheads in the resulting crop; the extreme limits of variations are 713 and 877 hogsheads, so that in general Governor Rawson proposes to predict the crop that will be gathered during the dry season, February to May, each year by simply multiplying the rainfall of the preceding calendar year by 800. The average uncertainties of the crop thus predicted is very small, the extreme error being 28 per cent positive following the wet year 1861 and 4 per cent negative for a certain dry year; therefore as an improvement on this method he adopts the rule of adding 7 per cent for wet years and subtracting 7 per cent for dry years, the average year being that which corresponds to 55 inches of rainfall.

In supplementary calculations Rawson and Walcott show the chances of a good crop as calculated from a large, small, or average rainfall, respectively, for each month of the year, but I do not find that they have at any time compared the crop with the total rainfall for the whole eighteen months or growing period that immediately preceded the crop, which comparison I have therefore made and give in Table III.

From all which it appears that large rains gives large crops, but occasionally much smaller rains do also, so that it may reasonably be suspected that here, as elsewhere, the sunshine must be considered; probably large rains are only of advantage when they occur at such a time that they do not diminish the sunshine and in such a manner that they do not wash the soil too severely.

It would have been desirable to have stated these crops as yields per acre rather than as total crops, but I find no statement of the actual acreage in cane. Rawson gives only the total areas of the six divisions of the island, which sum up 107,000 acres; probably two-thirds of this is planted in sugar cane, so that an inch of annual rainfall corresponds to $\frac{800}{71000}$, or one-ninetieth of a hogshead of sugar per acre.

It is, however, more proper to reason upon this matter as follows: Eleven poor crops gave, according to Table I, an average deficit of 15 per cent; 12 good crops gave an average excess of 14 per cent; the average rainfalls were 55.15 and 58.18, respectively. Therefore an increase of 1 inch in rainfall corresponds to a gain of $\frac{29}{3}$, or 10 per cent of an average crop.

TABLE I.—*Barbados sugar crop and monthly rainfall.*

Year.	Excess of sugar crop.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.
	Per cent.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1868	+29	4.29	1.74	1.93	0.97	1.68	3.45	6.26
1866	+27	3.75	2.75	1.57	1.26	2.74	2.63	6.23
1852	+21	3.30	1.58	1.53	2.17	7.11	2.17	2.49
1871	+20	4.13	2.29	1.07	0.56	0.98	2.71	3.65
1854	+17	2.64	1.95	1.43	1.20	1.33	5.56	5.68
1867	+14	2.68	4.49	0.88	1.64	2.66	10.94	7.50
1858	+13	1.52	1.28	1.40	0.96	2.23	4.54	3.69
1856	+11	1.73	2.18	1.19	0.81	2.94	5.49	2.86
1861	+10	3.49	1.96	2.76	6.35	8.01	9.31	8.28
1862	+ 2	7.60	1.12	0.31	1.12	3.53	7.18	5.39
1865	+ 2	2.36	2.19	1.39	4.13	5.89	9.19	7.35
1855	+ 1	6.96	2.95	1.85	5.49	6.82	6.61	8.00
1851	0	1.62	3.01	1.99	1.58	6.13	5.31	6.63
1853	0	4.04	3.94	2.38	3.38	9.26	5.21	3.89
1860	− 5	2.28	2.85	1.13	2.41	0.66	3.13	3.90
1863	− 6	1.19	3.88	2.26	2.26	0.56	1.62	8.65
1850	− 8	1.14	2.52	0.78	2.96	4.70	10.48	9.01
1859	−12	2.10	2.64	1.22	1.24	3.56	5.68	5.72
1870	−13	3.96	1.35	0.90	0.93	2.80	10.15	5.62
1857	−14	2.63	5.78	2.02	1.54	2.64	5.43	7.14
1849	−15	3.61	2.72	3.90	2.69	2.34	6.63	5.64
1847	−16	2.83	0.95	1.20	2.98	1.02	2.10	2.27
1864	−17	2.74	2.47	0.77	0.63	3.07	2.17	7.51
1848	−27	4.76	2.04	2.66	1.58	6.74	2.21	6.25
1869	−28	1.53	1.47	1.08	3.34	4.32	3.05	4.42
Average of 12 positive		3.70	2.21	1.44	2.22	3.82	5.80	5.62
Average of 11 negative		2.43	2.42	1.62	2.05	2.76	4.78	5.56
All (25)		3.26	2.58	1.47	1.99	3.54	5.45	5.70

Table I.—*Barbados sugar crop and monthly rainfall*—Continued.

Year.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual— Rain.	Annual— Crop.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Hhds.*
1868	5.62	4.63	8.20	4.42	1.40	44.60	58,250
1866	11.89	4.22	8.99	7.85	5.80	59.68	57,188
1852	7.36	3.72	6.53	14.15	6.66	58.77	48,611
1871	5.37	6.70	6.33	4.03	4.08	41.46	53,907
1854	5.11	3.97	7.03	11.19	3.79	50.88	45,181
1867	9.62	8.54	12.74	4.30	3.89	69.93	51,304
1858	4.24	3.54	10.46	6.13	5.22	45.22	50,788
1856	7.80	5.96	6.15	7.25	4.21	48.49	43,077
1861	4.65	6.77	7.60	7.50	7.11	73.82	49,745
1862	7.23	4.74	11.18	7.40	2.36	59.27	46,120
1865	8.91	5.07	11.00	4.53	6.58	63.64	46,068
1855	12.84	9.27	5.12	5.96	5.41	77.31	39,290
1851	7.00	9.25	6.53	4.29	6.05	59.40	38,731
1853	8.08	7.75	10.43	8.36	2.20	68.84	38,719
1860	7.93	7.31	13.30	7.97	5.09	57.91	42,684
1863	9.34	4.99	2.89	6.45	3.27	42.38	42,281
1850	6.82	3.34	10.17	9.61	6.36	67.88	35,302
1859	3.21	4.80	10.13	10.18	3.74	54.22	39,666
1870	5.61	5.03	11.24	8.37	3.38	60.17	39,270
1857	6.33	7.93	6.58	9.74	3.10	60.90	38,798
1849	6.82	4.74	8.53	1.42	3.73	52.77	33,077
1847	5.26	10.20	7.11	8.45	3.73	48.10	33,703
1864	7.37	10.77	9.14	6.31	6.16	59.19	36,199
1848	7.53	5.41	11.78	5.79	7.04	63.77	28,169
1869	6.95	4.56	6.99	5.13	5.73	48.52	32,150
Average of 12 positive	7.55	5.59	8.44	7.06	4.71	58.18	
Average of 11 negative	6.66	6.28	8.89	7.22	4.66	55.15	
All (25)	7.24	6.24	8.69	7.08	4.50	57.74	

TABLE II.—*Barbados sugar crop and rainfall of the growing period.*

Year.	Total rainfall of current year.	Crop.	Date of first shipment.	Total rainfall during growing season of the crop of current year.			
				All of preceding year.	Latter half of year before.	Total.	First half of year before.
	Inches.	*Hhds.*		*Inches.*	*Inches.*	*Inches.*	*Inches.*
1847	48.10	33,703	Jan. 21				
1848	63.77	28,169	Feb. 18	48.10			
1849	52.77	33,077	Jan. 21	63.77	37.02	100.79	11.08
1850	67.88	35,302	Jan. 22	52.77	43.80	96.57	19.97
1851	59.40	38,731	Jan. 18	67.88	30.88	98.76	21.89
1852	58.77	48,611	Jan. 17	59.40	45.31	104.71	22.57
1853	68.84	38,719	Feb. 12	58.77	39.75	98.52	19.65
1854	50.88	45,181	Jan. 19	68.84	40.81	109.65	17.96
1855	77.31	39,290	Feb. 17	50.88	40.71	91.59	28.13
1856	48.49	43,077	Jan. 23	77.31	36.77	114.08	14.11
1857	60.90	38,798	Feb. 14	48.49	46.62	95.11	30.69
1858	45.22	50,788	Feb. 10	60.90	34.25	95.15	14.24
1859	54.22	39,666	Mar. 7	45.22	40.82	86.04	20.08
1860	57.91	42,684	Feb. 6	54.22	33.28	87.50	11.94
1861	73.82	49,745	Feb. 17	57.91	37.78	95.69	16.44
1862	59.27	46,120		73.82	45.50	118.32	12.41
1863	42.38	42,281	Feb. 14	59.27	41.91	101.18	31.91
1864	59.19	36,199	Mar. 9	42.38	38.30	80.68	20.97
1865	68.64	46,068	Mar. 6	59.19	30.59	89.78	11.79
1866	59.68	57,188	Feb. 7	68.64	47.26	115.90	11.93
1867	69.93	51,304	Feb. 22	59.68	43.44	104.12	25.20
1868	44.60	58,250	Feb. 8	69.93	44.98	114.91	14.70
1869	48.52	32,150	Mar. 1	44.60	46.59	91.19	23.34
1870	60.17	39,270	Feb. 22	48.52	30.53	79.05	14.07
1871	41.46	53,907	Feb. 21	60.17	33.78	93.95	14.74
1872	48.36	39,167	Mar. 4	41.46	39.25	80.71	20.92
1873				48.36	30.16	78.55	11.30

Table III.—*Barbados sugar crop and rainfall of preceding year.*

Year.	Rainfall.	Above (+) or below (−) the average of crop of following year.	Year.	Rainfall.	Above (+) or below (−) the average of crop of following year.
	Inches.	*Per cent.*		*Inches.*	*Per cent.*
1855	77.81	+11	1864	59.19	+ 2
1861	73.82	+ 2	1852	58.77	0
1867	69.93	+29	1860	57.91	+10
1853	68.84	+17	1859	54.22	− 5
1865	68.64	+27	1849	52.77	− 9
1850	67.88	0	1854	50.88	+ 1
1848	63.77	−15	1869	48.52	−13
1857	60.90	+13	1856	48.49	−14
1870	60.17	+20	1847	48.10	−27
1866	59.68	+14	1858	45.72	−12
1851	59.40	+25	1868	44.60	−28
1862	59.27	+ 6	1863	42.38	−19

Note.—In calculating the average crop and the respective annual excesses or deficits given in Tables I and III Governor Rawson says that "he has made an arbitrary division of the whole period into two sections marked by the introduction of the use of guano as a fertilizer." For the first section, 1847–1856, inclusive, he considers 38,795 hogsheads as the average, but for the second section, 1857–1872, inclusive, he takes 45,036 hogsheads as the average. He states that this is virtually assuming that during the whole period climatic and other conditions were nearly constant and that the principal difference was in the introduction of the use of guano and the great increase of crops was due to that. During the first interval an inch of rain corresponded to 642 hogsheads of sugar in the crop of the next year, but during the second interval it corresponded to 800 hogsheads.

PART III.—STATISTICAL FARM WORK.

Chapter XIII.

THE CROPS AND CLIMATES OF THE UNITED STATES.

The ultimate object of our inquiry is to determine the exact percentage of the effect of normal and abnormal climates upon special crops in special regions of this country and the relation to the whole crop of the United States. To this end we must first ascertain the climatic effect on the yield per acre, and this is our present special problem, leaving it to the statistician and census taker to ascertain how many acres are under cultivation and what the actual effect will be in bushels or pounds. The climatologist, or Weather Bureau, has only to determine numerically the climatic effect upon a given unit area.

The tables of yield per acre for ten important crops and for all years will be given in a subsequent portion of this section, but the study of these must be preceded by several studies into matters that are not strictly climatic, but which nevertheless enter into the statistics of actual harvests and obscure the strictly climatic influences. Thus the statistics must be corrected in some way for the effect of the customary modes of cultivation and the quantity of seed that is sown, on which point I give statistics appropriate to the United States.

Again, before comparing our climatic data with the phenomena of vegetation we must know something of the average date of seeding, with respect to which I have given the dates for seeding of winter wheat.

The corresponding dates for rye will not differ very much. The dates for maize, potatoes, tobacco, and cotton have already been given for special localities, but still require to be tabulated in a general way. The necessary climatic data are given in my next section for twenty Signal Service stations, and I regret that the shortness of time has not allowed me to give more complete data for these and for all other stations, but the tables here presented will serve to show the form in which such data should be presented for the greatest convenience in phenological studies.

But before entering upon so extensive a system of numerical comparisons it is necessary to bear in mind certain principles which I would illustrate in the following remarks.

VARIABILITY OF RESULTS FROM PLAT EXPERIMENTS.

The reliability of the data obtained from experiments on small plats of ground, and on which we should naturally place much reliance in discussing the relation between climates and crops, is a matter of the first importance, and we must begin our study with an attempt to obtain a clear idea as to the extent to which such data are fit to be used as a basis for our studies. In the light of all that has thus far been ascertained with reference to the nature of the influences at work to increase or diminish the resulting crop, we may safely say that the results obtained from two different plats will not be comparable with each other and still less be applicable to the larger fields harvested by the farmers, unless we know for each plat or field the absolute or relative conditions as to the following matters:

(1) The mechanical condition of the soil as affecting aeration, percolation, and temperature.

(2) The chemical nature of the original soil.

(3) The character, proportion, and uniformity of distribution of the fertilizers and the history of the previous rotations of crops on these plats; the influence of climate, rain, and drainage on the available nutrition in the soil.

(4) The dates of cultivation and application of the fertilizers.

(5) The exact area of the plats.

(6) The distance apart of the hills or stalks.

(7) The number and quality of seeds sown per acre.

(8) The moisture in the soil at the beginning and the quantity and times of rain or irrigation.

(9) The chemical and biological quality of the rain or irrigation water—i. e., rain or snow water; rain with much or little nitrogenous compounds and biological germs.

(10) The injury by insects and animals.

(11) The temperature of the soil.

(12) The remaining climatic details as to heat, sunshine, dryness, and velocity of the wind.

(13) The sterility of the soil as to the microbic life that seems indispensable to the success of certain crops or to the growth of the plants.

(14) The nature of the climate in which the seed and its immediate ancestor was grown.

In the total absence of knowledge as to many of these points and fragmentary knowledge on others, a simple direct comparison between the results of two plats lying side by side and that have in some few respects been treated alike must be entirely misleading. But the extent to which such comparisons are deceptive, or rather the

extent to which we can rely upon them for further instruction, can only be estimated by a study of such exact experiments as have been made at the experiment stations throughout this country and Europe. Some illustrations of this matter are given by C. S. Plumb, under the title of the "Fallacies of plat experimentation" (Agr. Sci., Vol. II, p. 4), to which I will add the following remarks. Two sets of measures are taken from the results of the year 1887 at Geneva, N. Y. The plats were arranged in two series, or two fields, but were in every respect as much alike as possible and supposed to be identical. The harvests from the respective plats were as follows:

Plat.	Weight of good ears.		Plat.	Weight of good ears.	
	Series C.	Series E.		Series C.	Series E.
	Pounds.	*Pounds.*		*Pounds.*	*Pounds.*
1	237.2	223.8	14	172.8	177.5
2	224.2	216.9	15	171.8	167.1
3	222.7	199.0	16	172.6	182.2
4	242.0	222.2	17	183.4	150.1
5	264.2	196.1	18	....	140.2
6	232.9	174.2	19	....	128.2
7	155.3	182.7	Average	204.6	182.7
8	107.3	213.6			
9	222.2	197.6	Yield per acre.....bushels	51.1	45.7
10	243.8	186.0	Number of plants	12,380	12,820
11	224.6	168.1	Number of good ears	12,180	11,400
12	209.0	169.1			
13	191.7	177.6			

The individual differences between these 36 plats simply show that the conditions were not so uniform as the author supposed; in fact, the regular gradations from the high numbers at the top of the column to the low ones at the bottom show that there was a slight systematic difference among the plats in each series. On the other hand, the decided apparent differences between the two series, as well as between the plats, is very largely of the nature of those differences that are called accidental in the theory of exact measurements. Similar differences in a long series of observations of the temperature or the rainfall of any locality are spoken of not as accidental error but as the variability of the climate, and these differences in the present case may properly be treated as variability in the productive power of any plat compared with the neighboring plat without for the moment inquiring as to the cause of this variability. But the mathematical theory of probabilities, or chance, or errors of observation, is equally applicable to this question of variability due to unknown influences. According to that theory we obtain the index of variability if we take the difference between the average of a series and the individual num-

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bers in the series and treat these departures according to the following formula:

Index of variability of the plats equals

$$\pm 0.864\sqrt{\frac{\text{Sum of all the (Departures)}^2}{\text{Number of departures less 1,}}}$$

which formula may be interpreted as meaning that from the squares of the departures added together and divided by the number of plats less 1 we derive an index called the "probable uncertainty of 1 measure," or "the probable variability of 1 plat as compared with all the plats of the series." Again, knowing this uncertainty of any one measure, we find the "probable uncertainty of the average of n measures" by the following formula:

$$\text{Probable uncertainty of the average} = \pm \frac{\text{Index}}{\sqrt{n}}.$$

This latter formula is to be interpreted as meaning that there is an even chance that the computed average is too large or too small by this probable uncertainty. Applying these principles to the measures of plats C and E, I obtain the figures 34.3 and 22.9 as the indices of variability and 8.33 and 5.26 as the probable errors of the two averages. That is to say, so far as any internal evidence is given by the discrepancies between the measurements of the plats themselves, there is an even chance that the crop from a plat in series C is between the limits 212.9 and 196.3 or outside of these limits; similarly, for series E there is an even chance that the crop from any plat is within the limits 188.9 and 177.4 or outside of these limits. But the numbers within each of these two series overlap each other so much that it is perfectly possible that if we could increase the number of plats in each series sufficiently, all other conditions remaining the same, we should eventually arrive at very nearly the same average value for each. In other words, the mere difference of the two averages 204.6 and 182.7 is no evidence that in this particular case there was any important constant difference between the plats of series C and those of series E, but that, on the contrary, unknown sources of influence are at work in each series and in all the plats that are more important than any that were thought of when the experimenter endeavored to make these 36 plats perfect duplicates of each other.

Professor Plumb shows that this difference did not depend upon the previous crops or treatment of the plats during the previous five years. It certainly did not depend on the meteorological climate, the mechanical condition of the soil, nor on the seeds, nor on injury by insects and animals. We may possibly find a partial explanation in the irregular distribution of microbic life in the soil, but it is more likely that it depended upon the inherent variability of the

vitality of the seed, due to unknown causes, and which we have no means of measuring except by just such experiments as these. The elaborate measurements made by Lawes and Gilbert at Rothamsted, England, since 1850, furnish innumerable illustrations of this same principle; so, also, do those of W. R. Lazenby, at Columbus, Ohio, and many others.

We shall therefore hope to derive more reliable results from the study of farming operations on a large scale, taking the averages by counties and States where the crops have been carefully measured. We may possibly eliminate irregularities in many disturbing elements, and be able to clearly set forth that small percentage by which the crops of the United States as a whole are influenced by purely climatic conditions. Such influences may in extreme cases be very large, but, on the average, they are not so large as those which depend upon seed, cultivation, rotation, and fertilizers.

EFFECT OF VARIATIONS IN METHOD OF CULTIVATION AND IN QUALITY OF SEED FOR DIFFERENT REGIONS AND YEARS.

Among the modes of cultivation that materially affect the development of the plant and the quantity of the harvest must be considered the practice of sowing seed broadcast with the hand as contrasted with that of putting it in with the drilling machine. The drilling requires less seed, the saving being about one-half bushel per acre; the grain is buried more evenly, starts more uniformly, and stands the droughts better. Moreover, the drilled wheat fields are considered to yield more per acre, although it is difficult to state how much is due to the drilling independent of the character of the soil, because in general the fields that are drilled are most apt to be those free from stumps, stones, and steep slopes, while the broadcast sowing is especially adapted to this latter character of field. The census of 1879 shows that the drilled fields of winter wheat in Ohio yielded 50 per cent more than the broadcast fields of summer wheat in the Northwest; but it is not plain what proportion of this is respectively due to the drilling and to the soil.

In the report for 1875 of the Department of Agriculture (p. 42) the following statistics are given as to the percentage of area drilled, the quantity of seed per acre, and the increase of harvest in drilled fields over that in broadcasted fields:

The following table omits the New England States, which produce little wheat, nearly all of which is sown broadcast. The wheat area of New York is divided equally between the two methods. In New Jersey, Pennsylvania, Delaware, and Maryland the drill greatly predominates. In the Southern States the area is small, particularly in the cotton States, and the drill is comparatively unknown. North of the Ohio River, in the winter-wheat States, the drill is very

generally used, the proportion rising to 76 per cent in Illinois. In the spring-wheat region there are several reasons for prominence of broadcasting. One comes from a prevalent practice of sowing wheat on the irregular surface of a cornfield without plowing; another is found in the use of the combined cultivator and broadcast seeder, which destroys many of the weeds that would otherwise be left between the drills. * * * The result of the investigation shows that 47 per cent of the winter wheat and 30 of the spring, or 37 of both, represent the proportion seeded by the drill. The improvement by drilling is made to average 10 per cent. The average quantity of seed used for seeding winter wheat is 1.35 bushels per acre; 1.24 for drilled, 1.44 for the sown. The details are as follows:

Percentages for 1875.

State.	Relative area—		Increase of product by drilling.	Seed per acre.	
	Sown.	Drilled.		Broadcasting.	Drilling.
	Per cent.	*Per cent.*	*Per cent.*	*Bushels.*	*Bushels.*
New York	50	50	13	1.80	1.60
New Jersey	45	55	6	1.95	1.60
Pennsylvania	30	70	12	1.74	1.49
Delaware	26	74	10	1.75	1.50
Maryland	24	76	7	1.70	1.43
Virginia	62	38	12	1.44	1.21
North Carolina	97	3		1.07	0.83
South Carolina	99	1		1.00	0.70
Georgia	99	1		1.00	0.90
Alabama	99	1		1.00	
Mississippi	99	1		1.25	
Texas	98	2		1.18	0.90
Arkansas	100	0		1.10	
Tennessee	96	4	10	1.20	1.10
West Virginia	58	42	12	1.58	1.33
Kentucky	92	8	10	1.36	1.11
Ohio	39	61	16	1.57	1.33
Michigan	49	51	9	1.62	1.40
Illinois	24	76	19	1.52	1.24
Indiana	49	51	15	1.48	1.21
Missouri	62	38	21	1.52	1.21
Kansas	55	45	16	1.49	1.23
Nebraska	51	49	17	1.56	1.25
California	98	2		1.33	
Oregon	81	19	5	1.50	1.21

The following table, from the Agricultural Report for 1882 (p. 636), gives the proportion of winter wheat that was drilled and broadcasted in the autumn and winter of 1881 and 1882 for each State:

State.	Drilled.	Broad-casted.	State.	Drilled.	Broad-casted.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Connecticut	5	95	Louisiana	1	99
New York	52	48	Texas	11	89
New Jersey	56	44	Arkansas	2	98
Pennsylvania	70	30	Tennessee	15	85
Delaware	75	25	West Virginia	40	60
Maryland	68	37	Kentucky	31	69
Virginia	30	70	Ohio	78	22
North Carolina	8	92	Michigan	52	48
South Carolina	1	99	Indiana	81	19
Georgia	2	98	Illinois	71	29
Alabama	6	94	Missouri	58	42
Mississippi	1	99	Kansas	73	27

As it has not been practicable to obtain data that will accurately present the effect on the crop of the diverse features of cultivation that are independent of climate, I give, in addition to the preceding, the following general statements bearing on the annual crop statistics kindly communicated by Mr. J. R. Dodge, Statistician to the Department of Agriculture. Relative to the seeding and the stand of the crop and other matters, he says:

The practice varies with the kinds of corn. The small northern corn is planted closer than the larger more southern varieties. In the South corn is given greater distances than in the West. It grows larger there and makes more stalk growth and fewer ears. Only one or two stalks are planted in the hill there, while two or three in the middle, and three and even four in the extreme northern latitudes, are sometimes left in the hill. We have allowed one-third of a bushel per acre.

The individual differences in yield per acre in the States of highest, as well as of the lowest yield, are far greater than the differences in these State averages, as produced by differences in soil, in the effects of the various vicissitudes on different soils, in fertility or lack of it, in thoroughness of cultivation.

In the extreme West, beyond the Mississippi, where land is plenty and labor scarce, the cultivation is reduced to the minimum. Satisfactory results are now produced in southern Iowa in winter-wheat growing by simply "cultivating" between corn rows and sowing wheat at a labor expense of 60 cents per acre. The rough surface is favorable for exemption from winter killing, and some records of experiment show an increase of 25 per cent in yield over planting after clover on a smooth surface. This is so notwithstanding the clover soil might be expected to have something like as great an advantage in real fertility over the soil that had grown a crop of maize. The corn exhausts, the clover enriches, and still the yield is

the greater after the corn, because the plants are not much injured by frost.

EFFECT OF VARIATIONS IN DATES OF SEEDING AND HARVESTING.

The injurious effects of late frosts on early vegetables and on grains sown in the spring is generally annulled in part by a second sowing, so that the crop reports for the year do not show the full extent of the injury done to the plant by the climate.

In a general comparison between the climate and the crops accuracy would require that we know the date of last planting, but in the absence of this fundamental datum we are obliged to use the average dates between which the planting is done in any given State, and such dates are given in the following table and are assumed to refer to the dates of planting the seed which actually brought forth the subsequent harvest, whose yield per acre is given in the tables published by the statistician of the Department of Agriculture.

These tables are also necessary in order to compute the thermal constants and to anticipate the dates of bloom and harvest. The following tables, for 1882 and 1889, as published in the Annual Reports of the Department of Agriculture (pp. 409 and 636, respectively), give the dates of seeding for wheat:

State.	1882.			1889.		
	Date of seeding.		Average date of seeding.	Date of seeding.		Average date of seeding.
	From—	To—		From—	To—	
Connecticut	Sept. 1	Nov. 1	Sept. 25	Sept. 1	Oct. 25	Sept. 25
New York	Aug. 15	Oct. 30	Sept. 16	Aug. 15	Oct. 15	Sept. 15
New Jersey	Aug. 28	Nov. 10	Sept. 28	Aug. 25	Oct. 25	Sept. 25
Pennsylvania	Aug. 20	Oct. 20	Sept. 20	Aug. 10	Oct. 30	Sept. 19
Delaware	Sept. 20	Oct. 10	Oct. 1	Sept. 15	Nov. 1	Oct. 10
Maryland	Sept. 1	Dec. 1	Oct. 13	Aug. 20	Nov. 20	Oct. 13
Virginia	Aug. 20	Nov. 25	Oct. 15	Sept. 5	Dec. 1	Oct. 19
North Carolina	Sept. 1	Jan. 10	Oct. 29	Sept. 1	Dec. 15	Nov. 5
South Carolina	Oct. 1	Jan. 1	Nov. 1	Oct. 1	Dec. 10	Nov. 13
Georgia	Sept. 1	Jan. 10	Nov. 2	Sept. 1	Dec. 25	Nov. 14
Alabama	...do...	Dec. 20	Nov. 8	Sept. 15	Jan. 1	Nov. 7
Mississippi	...do...	Dec. 1	...do...	...do...	Dec. 30	Nov. 5
Louisiana	...do...	Nov. 20	Nov. 5			
Texas	...do...	Mar. 15	Nov. 7	Sept. 1	Feb. 1	Nov. 6
Arkansas	...do...	Jan. 15	Oct. 26	...do...	Jan. 10	Nov. 1
Tennessee	Aug. 1	Dec. 15	Oct. 15	...do...	Dec. 20	Oct. 22
West Virginia	Aug. 20	Nov. 15	Sept. 30	...do...	Nov. 15	Oct. 2
Kentucky	Aug. 25	Dec. 20	Oct. 7	...do...	Dec. 10	Oct. 12
Ohio	Aug. 1	Nov. 20	Sept. 20	Aug. 25	Nov. 15	Sept. 24
Michigan	Aug. 20	Nov. 15	Sept. 17	Aug. 20	Nov. 1	Sept. 15
Indiana	Aug. 15	...do...	Sept. 19	...do...	Nov. 20	Sept. 24
Illinois	Aug. 20	Nov. 10	Sept. 20	Aug. 25	Nov. 13	Sept. 23
Missouri	Aug. 15	Dec. 1	Sept. 25	Aug. 15	Dec. 1	Sept. 29
Kansas	Aug. 1	Jan. 1	Sept. 23	...do...	...do...	Sept. 24
California				Sept. 1	May 1	Dec. 27
Oregon				Sept. 15	Apr. 1	Nov. 25

The following table gives dates of sowing and ripening, especially in America additional to those given by Lippincott (1863), and in many cases will give useful indications of the progressive change that has gone on since 1860 in methods of cultivation and in the habits of the wheat itself:

Locality.	Latitude north.	Date of sowing.	Date of reaping.	Duration.	Variety of wheat and remarks.
	° ′			*Days.*	
Delta of Egypt		Nov. —	May —	180	
Europe.					
Malta		Dec. 1	May 13	163	
Palermo, Sicily		do	May 20	170	
Naples		Nov. 16	June 2	195	
Rome		Nov. 1	July 2	242	
Alps:					
3,000 feet		Sept. 12	Aug. 7	329	
4,000 feet		Sept. 8	Aug. 14	340	
Central Germany		Nov. 1	July 16	137	
South of England			Aug. 4		
Middle of Sweden			do		
United States.					
Aroostook County, Me.	46 47	May 15	Sept. 1		
Franklin County, Me.	45 00	May 20	Sept. 20		
Penobscot County, Me.	45 00	May 21 to June 1	Aug. 15		
Somerset County, Me.	45 00	May 25 to June 1	Aug. 20 to Sept. 20		
Washington County, Me.	45 00	Apr. 10 to May 10	Sept. 10-20		
St. Lawrence County, N. Y.	44 40	Apr. to June	August		
Do	44 40	Sept. to Nov	July		
Windsor County, Vt.	43 30	Sept. 18	July 25		
Oshkosh County, Wis.	44 00	Sept. 1	Aug. 15		
Walworth County, Wis.	43 00	Sept. 1-15	July 20		
Hillsdale County, Mich.	42 00	Sept. 10-25	July 10-20		
Wayne County, Mich.	42 15	Sept. 5-25	July 5-15		
Washtenaw County, Mich.	42 15	Sept. 1-20	July 8-20		
Genesee County, N. Y.	43 00	Aug. 15 to Sept. 15	July 25		
Livingston County, N. Y.	42 45	Sept. 15	July 20 to Aug. 20		
Ontario County, N. Y.	42 45	Aug. 20 to Sept. 25	July 15 to Aug. 1		
Monroe County, N. Y.	43 00	Sept. 25	July 8		May.
Seneca County, N. Y.	42 45	Sept. 10-20	July 20		
Do	42 45	Sept. 2	July 13		Dayton.
Ulster County, N. Y.	41 45	Sept. 1-20	July 10-20		Mediterranean.
Steuben County, N. Y.	42 15	Aug. 25 to Sept. 10	July 25		
Hampshire County, Mass.	42 00	Sept. 5	do		

Locality.	Latitude north.	Date of sowing.	Date of reaping.	Duration.	Variety of wheat and remarks.
	° ′			*Days.*	
Madison County, Iowa.	42 00	September	July 6-18		
Scott County, Iowa.	42 00	April	July		Spring.
Henry County, Iowa.	41 00	September	July 1		
Marion County, Iowa.	41 00	Apr. 1-20	July 15		Do.
Do	41 00	Aug. 15 to Sept. 20	July 4		
Lee County, Iowa	40 45	September	July 5-12		
Menard County, Ill.	40 00	Oct. 1-15	June 28 to July 10		
St. Clair County, Ill.	38 30	Sept. 28 to Oct. 18			
Howard County, Mo.	39 00	Sept. 1 to Oct. 30	June 30		
Delaware County, Ind.	40 15	Sept. 15	July 1-15		
Rush County, Ind.	39 30	September	June 25 to July 5		
Wayne County, Ind.	39 45	Sept. 1 to Oct. 15	June 25 to July 7		
Harrison County, Ohio.	40 15	Sept. 1-20	July 1-10		Soule.
Athens County, Ohio.	39 30	Sept. 3	July 1		
Clinton County, Ohio.	39 20		July 4		Rock.
Lawrence County, Ohio.	38 40	October	May 30		May.
Mahoning County, Ohio.	41 00		July 15		Mediterranean.
Fairfield County, Ohio.	39 45		June 15 to July 1		Do.
Westmoreland County, Pa.	40 30	Sept. 10 to Oct. 15	July 3		
Fayette County, Pa.	40 00	Sept. 1-20	July 7		Do.
Mifflin County, Pa.	40 30	Sept. 10 to Oct. 1	July 1		
Dauphin County, Pa.	40 30	Sept. 1 to Oct. 1	July 4-15		
Berks County, Pa.	40 30	Sept. 10-15	July 4-20		Blue Stem.
Philadelphia County, Pa.	40 00	Sept. 15 to Oct. 15	July 15		Mediterranean.
Bergen County, N. J.	41 00	Oct. 1	July 5-15		
Gloucester County, N. J.	39 45	do	July 1-10		
Salem County, N. J.	39 30	Sept. 30 to Oct. 7	June 25 to July 1		Do.
Newcastle County, Del.	39 00	Sept. 20 to Oct. 10			Do.
Dover County, Del.	39 00	do	June 15-23		
Sussex County, Del.	38 50	Sept. 28 to Oct. 15	June 25 to July 1		
Harford County, Md.	39 45	Sept. 1 until frost	June 25 to July 15		
Jefferson County, Va.	39 15	Sept. 25 to Oct. 15	June 25 to July 1		
Do	39 15	Sept. 4-23	July 22		Do.
Richmond County, Va.	37 50	Sept. 16, 1859	June 14, 1860		Japan.
Do	37 50		June 2		Early Conner.
Do	37 50		May 26, 1842		May.

Locality.	Latitude north.	Date of sowing.	Date of reaping.	Duration.	Variety of wheat and remarks.
	° ′			*Days.*	
Franklin County, Va.	37 00	Oct. 1 to Dec. 15	June 20 to July 10		
Buckingham County, Va.	37 40	Oct. 1 to Nov. 15	June 15 to July 4		
Mason County, Ky	38 30	Sept. 1 to Oct. 15	June 2		Early May.
Clark County, Ky.	38 00	Sept. 15 to Oct. 30	June and July		
Logan County, Ky	37 00	October and November.	June 10–30		
Cabarras County, N. C.	35 30	November	June 1–10		Do.
Bedford County, Tenn.	35 30	Sept. 15 to Nov. 15	June 1–14		
Habersham County, Ga.	34 45	Sept. 15 to Dec. 1	June 15 to July 15		
Cherokee County, Ala.	34 15	Oct. 1 to December.	June 1–15		
Montgomery County, Ala.	32 30		May 31		
Gaudalupe County, Tex.	30 00	Jan. 1	June 1		
Santa Fe, N. Mex.	35 40	April	August		
Albuquerque, N. Mex.	35 10	February and March.	July 31		
Donna Ana County, N. Mex.	32 30	Jan. 15	August		
Utah Territory	43 00	Sept. 1 to May 1	June to September		
Stanislaus County, Cal.		November	June 1		White Chili.
British North America.					
Fort Fraser	54 30				West of the Rocky Mountains.
Cumberland House, on Saskatchewan River.	53 57				Sown May 8; reaped in August.
Red River settlement.	50 00				Wheat grows luxuriantly.
Fort Francis, Rainy Lake district.	48 36				Sown May 1; reaped in August (120 days).
Quebec, Canada	46 49				Wheat succeeds.
Prince Edward Island.	46 12				Extensively grown.
Fredericton, New Brunswick.	46 00				Wheat succeeds.
Pictou, Nova Scotia.	45 34				August mean, 63; wheat succeeds.
Beyond north polar limit of successful wheat culture.					
Sitka, Alaska	57 00				Wheat does not ripen.
Fort York, on Hudson Bay.	57 00				Do.
Edmonton, on Saskatchewan River.	53 40				Often destroyed by frost.
Carlton House, on Saskatchewan River.	52 51				Do.
Fort Liard, McKenzies River.	60 00				Grows occasionally.
St. Johns, Newfoundland.	47 33				Wheat does not ripen.

BRIEF SUMMARY OF CONCLUSIONS.

Some of the principal points that have been brought out in this collection of data will seem like the expression of ideas that have long been known, yet whose importance has probably been underrated by those who desired to deduce definite numerical relations between the climate and the crops of any locality.

(1) We have seen that in a general way the plant, like every other living being, adapts itself, when possible, to its climatic surroundings, and therefore will produce some crop, if possible, the first year and will do better and better in the next few succeeding years if the seasons are not too sèvere.

So sensitive is the plant to a change of environment that the ordinary seasonal irregularities from year to year have a strong influence upon it, so that the general disposition acquired by the seed in a single dry or wet, or cold, or early, or late season prepares it for a corresponding dry or wet, cold, early, or late season next year. Or, again, a "sport" that has unexpectedly developed under the special influence of a given season and soil, and has acquired to a high degree characteristics which make it harmonize with that season, becomes the progenitor of some important variety whose adoption may, in a few years, revolutionize the agriculture of that region. The weather of any growing season affects the crops of future years by modifying the seeds of the current crop. The current season and the resulting seeds must harmonize together.

(2) If, instead of adapting the plant to the climate, we, for instance, plant the seeds proper for a moist climate in an arid region, and if we must therefore artificially irrigate in order to secure a crop, such irrigation should be looked upon, not as establishing an expensive custom to be adhered to in future ages, but as simply a temporary device to be managed in the interests of the evolution of new varieties that can eventually be cultivated in that soil and climate without irrigation. This is the result that nature has herself frequently achieved by the slow process of carrying seeds, step by step, from moist to arid regions, and which man endeavors to hasten when he carries seeds by railroad and steamship from England to our arid region.

(3) Inasmuch as the cultivation of the cereals cotton, tobacco, sugar, and other important crops will hardly be attempted except in regions where the climate is known to be reasonably in harmony with the seed that is planted, therefore we may assume that an average crop is certain under the average climatic conditions. The departure of any special season as to climate will produce a corresponding departure as to crop, but the latter must be expressed as a percentage of the average ordinary crop, and not simply in absolute measure,

as bushels or pounds, since the absolute crop depends so much upon the soil, the manuring, the cultivation, the thickness of seeding, and other details. On the other hand, the crop of one season must have some relation to the crop of the preceding season by reason of the inherited tendencies of the seed from which it was raised. The climatic factors $\frac{\text{rainfall or useful moisture}}{\text{temperature or heat}}$ and $\frac{\text{rainfall or nutriment}}{\text{sunshine}}$ are, as shown by Linsser, the data that must be compared with the resulting harvests.

(4) It is evident that the question of the effect of climate on a given crop in the past is not so important as the prediction of what crop will be harvested from a given field already planted. On this point I have given all the illustrations that I could find, especially in Chapter XII, showing how from an analysis of a sample at any given date one should be able to predict the resulting crop. The result can be made correct to within 10 per cent, if we allow for the ordinary average irregularities of the climate, a statement of whose extent can easily be made up from meteorological records. As to extraordinary irregularities of climate which can not be foreseen, I remark:

(*a*) First of all the effects of excessive droughts at each stage of the plant can be estimated from the experimental data given in Part I, and will be found to harmonize as well as could be expected with the results of actual experience as given in Part II:

(*b*) The effect of severe unusual droughts, or heat, or cold, or moisture are ordinarily felt over relatively small portions of the country, so that the average result is small in comparison with the whole crop available in the country; for instance, in 1890, in Kansas and Nebraska the corn harvest was one-half of its usual amount and almost the same in 1887, reckoning, of course, the yield per acre, but this and the corresponding small yields in a few other States represent only an inappreciable percentage of loss to the country at large.

(5) The studies of the effect of climate on the daily development of sugar in beets, sugar cane, or sorghum, or on the nutritious harvest of grass and cereals has shown the approximate best dates for harvesting these crops.

(6) The studies of the physiological importance of the leaves of beets will eventually show whether these should be trimmed or how they should be treated in order to stimulate the production of sugar. As the pruning of hop vines and grapevines stimulates the ripening and increases the amount of the crops, and as the plucking of the tassels from the maize apparently increases that crop, and as the plucking of the flowers and balls from the potato vines increases the growth of the tubers, so doubtless in many other ways the methods of

cultivation may be made to simulate the effects of a favorable climate, so that in general we are justified in the conclusion that while uncultivated plants and their fruits are wholly dependent on the weather, yet methods will be found by which we may render the harvests from cultivated plants largely independent of the weather.

(7) The data here collected demonstrate that the richness of the soil determines the amount of the annual cereal crop more than does the climate. The latter determines principally the dates of sowing, ripening, and the immunity from early or late frosts or the possibility of bringing the plant to maturity.

(8) We see that rain or irrigation water, so necessary as the medium for bringing the nitrogenous molecules from the soil up into the seed cells of the plant, also by drainage and seepage carries away any such molecules if these are present as earths or manures, whereas if these are present in living microbic or rotting leguminous cells they are far more available for plant use. The best method by which the nitrogen of the free air is thus made available for agriculture is elaborated in chapters VIII and IX.

(9) From the data now at hand I should say that the yield per acre for any one of the ten principal crops whose statistics are here given has probably never been either increased or diminished by 50 per cent of the normal yield per acre by climatic influences alone over any large region, such as 100 square miles, and, further, that the total annual harvest for any given crop in the United States is not likely to be diminished 5 per cent by the occurrence of an inclement season in some one portion of the country.

The detailed comparison of the climate for each season with the crop for that season has become practicable to me only since completing the table of statistics in this chapter, and it is as yet too soon to anticipate all the results that will follow therefrom.

Note.—As these statistical tables are very voluminous and only extend to the year 1890 their publication has been deferred until they can be brought up to date. They will probably form a continuation of this present text.—C. A.

PART IV.

Chapter XIV.

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INDEX.

In this index special attention has been paid to the spelling of proper names, and in case of any discrepancy being detected between the index and the text, the reader will kindly consider the former as the proper authority.

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